AL/CF-TR-1994-0046

AD-A284 055

ARMSTRONG LABORATORY

THE CROSS-VALIDATION OF THE UNITED STATES AIR FORCE SUBMAXIMAL CYCLE ERGOMETER TEST TO ESTIMATE AEROBIC CAPACITY

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June 1994

Interim Technical Report for Period June 1993 - June 1994

AIR FORCE MATERIEL COMMAND

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This report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1994

3. REPORT TYPE AND DATES COVERED
Interim June 1993 - June 1994

4. TITLE AND SUBTITLE
The Cross-Validation of the United States Air Force Submaximal Cycle Ergometer Test to Estimate Aerobic Capacity

5. FUNDING NUMBERS
C - F33615-90-D-0606
PE - 62202F
PR - 7930
TA - 14
WU - 06

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory (AFMC)
Crew Systems Directorate
Crew Technology Division
2504 D Drive, Suite 1
Brooks Air Force Base, TX 78235-5104

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/CF-TR-1994-0046

11. SUPPLEMENTARY NOTES
Armstrong Laboratory Technical Monitor: Lt Col Roger U. Bisson, (210) 536-3464.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Two hundred and seven subjects (males, n=103; females, n=104) between the ages of 18 and 54 volunteered for this study to determine the accuracy of the USAF submaximal cycle ergometry (SCE) test versus treadmill (TM). The analysis shows that USAF SCE VO_{2max} estimates are valid for males and females in this age range. For males, baseline SCE underpredicted VO_{2max} by 2.2 ml/kg.$^{-1}$/min^{-1}, had a moderately high correlation (r=0.85), and acceptably low standard error of the estimate (SEE, 6.7 ml/kg.$^{-1}$/min^{-1}). For females, baseline SCE overestimated VO_{2max} by 2.2 ml/kg.$^{-1}$/min^{-1}. For females, correlation was moderately high (r=0.85) with a relatively low SEE (5.5 ml/kg.$^{-1}$/min^{-1}, 16.6%). Repeat SCE did not increase accuracy. Adjusting power output to achieve higher steady state heart rates improved correlations and lowered SEE. SCE was more closely related to TM VO_{2max} than to maximal cycle measures. Finally, 102 subjects completed a YMCA SCE test. For males, the YMCA test overpredicted VO_{2max}. Correlation and SEE were not satisfactory (r=0.63 and SEE=9.8 ml/kg.$^{-1}$/min^{-1}). For females, the YMCA test was equally good or slightly better than the USAF SCE in estimating VO_{2max}. USAF SCE sensitivity was 75%. Specificity was 96%. Suggestions to further improve USAF SCE validity and accuracy are offered.

14. SUBJECT TERMS
Aerobic capacity
Cycle ergometry
Physical fitness

15. NUMBER OF PAGES
160

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

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Summary

Two hundred and seven subjects (males, n=103; females, n=104) between the ages of 18 and 54 years of age volunteered to participate in the U.S. Air Force (USAF) cross-validation study to determine the accuracy of the USAF submaximal cycle ergometer (SCE) test. Of these subjects 134 completed phase I of the project by completing a baseline SCE test, a maximal treadmill test to determine maximum aerobic capacity ($\dot{V}O_{2max}$), and two additional SCE tests (SCE 1 and 2). Additionally, 113 subjects who completed phase I also completed the SCE 3 and 4 tests and a maximal cycle ergometer test to determine $\dot{V}O_{2max}$ (phase II). Finally, 102 subjects completed both phases I and II of the project and completed a submaximal cycle ergometer test developed by the YMCA (phase III).

The USAF SCE test was cross-validated with phase I subjects who were divided by gender (males n=67, females n=67). The analysis showed that the USAF SCE test is a valid test for use with males and females between 19 and 54 yr of age. The cross-validation statistics for males showed that the baseline SCE test underpredicted the actual treadmill $\dot{V}O_{2max}$ by 2.2 $ml \cdot kg^{-1} min^{-1}$, had a moderately high correlation (r=0.85), and acceptably low standard error of estimate (SEE, 6.7 $ml \cdot kg^{-1} min^{-1}$, 14.0%). For the females, the baseline SCE test overestimated the $\dot{V}O_{2max}$ compared to the treadmill test by 2.2 $ml \cdot kg^{-1} min^{-1}$. The correlation of the SCE baseline test for females was moderately high (r = 0.84) with a relatively low SEE (5.5 $ml \cdot kg^{-1} min^{-1}$,

16.6%). Compared to the baseline SCE, the SCE test 1 and 2 showed no further increase in accuracy for either the males or the females. Repeat testing (SCE 1 vs. SCE 2) showed the test to be highly repeatable (reliable). The mean values for $\dot{V}O_{2max}$ estimates from the SCE 1 and 2 tests were similar to the treadmill maximum values for male subjects, but continued to overestimate the $\dot{V}O_{2max}$ compared to the treadmill values for females.

Further evaluation of the equations based on age, fitness level, and cycling experience showed that level of fitness was an important confounding factor. Fitness level was defined as low-fit which included subjects from USAF fitness categories 1, 2, and 3 (based on the treadmill maximum aerobic capacity test). The high-fit group was selected from USAF fitness categories 4, 5, and 6. For males, a large significant underprediction of estimated $\dot{V}O_{2max}$ from the baseline SCE test was found compared to the treadmill test (-5.8 $ml \cdot kg^{-1} min^{-1}$) in low-fit males. This underprediction did not occur for the high-fit males or the low-fit females. In contrast, the estimated $\dot{V}O_{2max}$ of the high-fit females significantly overestimated the baseline SCE test values compared to the treadmill $\dot{V}O_{2max}$ (5.5 $ml \cdot kg^{-1} min^{-1}$). Therefore, the baseline SCE test was considered to correlate well and have an acceptable low SEE compared to the treadmill determined $\dot{V}O_{2max}$. But the data show that the mean $\dot{V}O_{2max}$ values for males were significantly underestimated by the subjects in the USAF low-fit categories and overestimated by the female subjects in the high-

fit categories. Thus, the refinement of these equations would make them very acceptable for use with the total U.S. Air Force population.

Phase II of the project showed that the additional SCE 3 and 4 tests, which manipulated the power output on the SCE test $\pm$ 0.5 kp depending on the subject's maximal, treadmill heart rate, did not improve the reliability of the test. But when subjects were separated as to the SCE tests that estimated $\dot{V}O_{2max}$ from a lower steady heart rate compared to a higher steady state heart rate, differences in validity occurred. That is, subject's $\dot{V}O_{2max}$ estimated from a higher steady state heart rate resulted in a higher r and lower SEE.

The maximal cycle ergometer test to determine $\dot{V}O_{2max}$ showed a 12 and 13% underprediction of the treadmill test to determine $\dot{V}O_{2max}$ for males and females, respectively. It is very clear from the results that the baseline SCE test was closely related to the treadmill $\dot{V}O_{2max}$ test and not the cycle ergometer $\dot{V}O_{2max}$ test.

Phase III of this cross-validation study included a comparison of the YMCA test and the USAF SCE test for estimating $\dot{V}O_{2max}$. For the males, the YMCA test overpredicted the $\dot{V}O_{2max}$ compared to the treadmill test and the r and SEE were not satisfactory ($r = 0.63$, SEE = 9.8 $ml \cdot kg^{-1} min^{-1}$, 20.3%). In contrast, for females, the YMCA test was equally as good (or slightly better) as the baseline SCE test in estimating $\dot{V}O_{2max}$.

An important issue concerning the USAF SCE test is the large number of invalid tests that occur on initial testing, that is

the baseline SCE test. The data show that of the 207 SCE tests administered for this project, 57(28%) were classified as invalid using the USAF software. Most of the invalid tests (79%) were due to the subject's heart rate exceeding that which is acceptable for the computer logic design to accurately calculate $\dot{V}O_{2max}$. That is, heart rate exceeded the value of 85% of the subject's maximum heart rate based on 220 - age. The other factor that caused invalid tests was the computer algorithm which increased the power output excessively so that the subject fatigued and could not complete the protocol. Comparatively, the YMCA protocol only had two invalid tests. Thus, the USAF test in its current form would not be acceptable with such a high failure rate. A later discussion will give suggestions as to how to improve the invalid test rate.

Because of some of the problems associated with the current USAF SCE test prediction equations for estimating $\dot{V}O_{2max}$, a stepwise multiple regression analysis was completed to generate new equations. In general, using the same basic variables as the current USAF SCE test, the predictions were approximately the same for both males and females. The slightly higher correlations and lower SEEs found with the newer equations (Tables 21 and 22) were probably biased because the results were derived from the data of the same population (current study). That is, a cross-validation study with another group of volunteers would probably lower the correlation and increase the SEE. The equations that were developed at Armstrong laboratory

were cross-validated with the results of the study conducted at the University of Florida.

When body composition variables were included in the regression model, such as % body fat and fat free mass, as well as the use of a log or squared variable regression model, the newly developed equations improved in accuracy and appear to be superior to the current equations used in the USAF SCE test. This cannot be fully answered until cross-validation studies of the newer equations are conducted.

The final aspect of the study looked at sensitivity and specificity of the baseline SCE test. The test showed a sensitivity of 75% and a specificity of 96%. Thus, some subjects were definitely mis-classified. The most important problem with mis-classification would be a false positive test, that is those subjects who would fail the USAF minimum standard for aerobic capacity (fitness category 1 or 2) based on the results of the SCE test, but would actually pass the test according to the measured treadmill VO_{2max}. Five of 134 persons tested (3.7%) were classified as false positives in this study. Although this number is small, extrapolating over the USAF population would make the problem significant. It is clear from the results of the cross-validation study, that the subjects who would have the largest risk of becoming a false positive based on the current SCE test, would be male subjects in fitness category 3.

Introduction

For years the U.S. Air Force (USAF) has been interested and aware of the importance of aerobic endurance fitness for the health and well being of its personnel. Also, aerobic fitness has been associated with better job performance. In the late 1960's and early 1970's Lt. General Richard Bohannon, M.D., surgeon general of the USAF, recognized the importance of aerobic fitness for all USAF personnel and the need for a proper test for its evaluation. The "gold standard" for aerobic fitness assessment, a physician-monitored maximal treadmill test, was impractical for use on a half-million USAF personnel because of the time, technical staff, and equipment requirements. Lt. Col. Kenneth Cooper, M.D. found an initial solution to the problem with the development of the 12 minute run test to estimate treadmill determined maximum aerobic capacity (1). It was later modified to a 1.5 mile run test which was adopted for use by the USAF.

The 1.5 mile run test is an adequate field test for estimating aerobic capacity (see review of literature section) but had many problems in its implementation and administration (2). Administering a maximal running test was not a safe procedure because most USAF personnel were not accustomed to high intensity exercise. Also, many USAF personnel did not prepare themselves for the test and had to perform it under adverse environmental conditions. Motivation is always a major problem associated with getting accurate estimates of aerobic capacity

from running field tests.

Recently, the USAF adopted a modified Astrand-Rhyming submaximal cycle ergometer (SCE) test to estimate maximum aerobic capacity for annual fitness testing. The test was validated for USAF use at the Armstrong Laboratory, Brooks Air Force Base, San Antonio, TX. Cross-validation testing was still needed to determine prediction accuracy of this new SCE test, especially since USAF feels its members should meet the USAF category 3 fitness standard. Also, problems related to test administration (invalid tests) and miss-classification of USAF personnel into the wrong fitness category needed to be addressed. Therefore, in May, 1993 the Center for Exercise Science, University of Florida, Gainesville was contracted to do an extensive cross-validation of the USAF SCE test.

This report contains the cross-validation results obtained from extensive testing performed at the Center for Exercise Science. The data were collected on 67 males and 67 females, 19 to 54 years of age, who were healthy volunteers and could meet the USAF medical health standards. This report consists of four sections: (1) Review of Literature, (2) Methods, (3) Results and Discussions, and (4) Conclusions and Recommendations.

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1. Cooper, K.H. Correlation between field and treadmill testing as a means for assessing maximal oxygen intake. JAMA 203:201-210, 1968.

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REVIEW OF LITERATURE

INTRODUCTION

The ability to perform long-term muscular work depends on the bodies ability to supply energy. Energy production for endurance type work is dependent upon aerobic metabolism, or the amount of oxygen utilization ($\dot{V}o_2$). Maximal rate of oxygen consumption, or $\dot{V}O_{2max}$, defines maximal aerobic capacity. $\dot{V}O_{2max}$ is an important indicator of fitness and cardiovascular health (64,72). $\dot{V}O_{2max}$ is also correlated with endurance performance; for example, trained oarsmen have about twice the $\dot{V}O_{2max}$ compared to untrained subjects (24).

When selecting persons for special tasks during military service, it is important to know the fitness levels of these individuals. Fitness is determined in part by an individuals aerobic capacity, strength, flexibility, and coordination. When classifying fitness levels, it is desirable to have criterion measures from each catagory. However, when limited to a single test to predict fitness it is reasonable to test aerobic capacity due to its high correlation with prolonged muscular work. A greater $\dot{V}O_{2max}$ would, in general, indicate a greater ability to perform prolonged muscular work.

DETERMINANTS OF OXYGEN UPTAKE

During muscular work, $\dot{V}o_2$ is related to the intensity and duration of the exercise and the amount of muscle mass required to perform the task (5). The ability to meet these demands is determined by the ability of the cardiovascular system to deliver

oxygen to the working muscles and the ability of those muscles to utilize the oxygen for energy production.

Oxygen Delivery - Oxygen delivery is defined as

$$\dot{Q} \times [O_2]_a$$

where $\dot{Q}$ is the cardiac output and $[O_2]_a$ is arterial oxygen concentration.

Cardiac output is defined as the quantity of blood pumped by the heart each minute (24), which is the product of stroke volume and heart rate. Stroke volume is the volume of blood ejected by the left ventricle with each heart beat and the heart rate is a measure of the frequency of contraction.

During aerobic exercise, cardiac output can increase up to five fold from resting values in untrained people and up to 7 fold from resting values in trained people (normal cardiac output for a trained or untrained adult is 4-5 $L \cdot min^{-1}$). With the increase in metabolism during aerobic exercise, substrate and oxygen delivery to working muscles must be increased. This increased delivery is accomplished by increasing cardiac output.

Distribution of cardiac output throughout the body is largely determined by metabolic demand. At rest, 15-20% of cardiac output is distributed to skeletal muscles. During intense exercise, as much as 85% of cardiac output may be directed to the working muscles. Note that these percentages are altered little by training. However, endurance training does increase exercise cardiac output, so blood flow to working muscles increases.

Arterial oxygen concentration ($[O_2]_a$) is determined by the hemoglobin concentration of blood and barometric pressure, which dictates the driving pressure of oxygen. Oxygen binds to hemoglobin in the lung, and then is delivered to peripheral tissues. Approximately 97% of hemoglobin in arterial blood is bound with oxygen at sea level. Normal hemoglobin concentration is approximately 15 mg/dl. Endurance training has little or no effect on binding of oxygen to hemoglobin; thus, untrained and trained people have similar (97%) arterial hemoglobin oxygen saturation. Thus, oxygen delivery to working muscles is mainly determined by muscle blood flow.

Oxygen Utilization - Oxygen utilization at the muscle level is dependent upon aerobic enzyme capacity and mitochondrial concentration. The activity of aerobic enzymes and amount of cellular mitochondria present directly effect oxygen uptake at the cellular (muscle) level, i.e. the more mitochondria and enzymes present, the greater the capacity for oxygen uptake. Aerobic (endurance) training increases the amount of mitochondria and aerobic enzyme activity. Thus, endurance training can directly increase oxygen utilization by the muscles during exercise. Venous blood draining from working muscle has less oxygen than arterial blood. This difference is known as the a-vO_2 difference.

In summary, $\dot{V}o_2$ is determined by oxygen delivery and utilization which is summarized by the following equation of Fick:

$$\dot{V}o_2 = \dot{Q} \times (a\text{-}vO_2)$$

where $\dot{Q}$ is the muscle blood flow and $a\text{-}vO_2$ is the arteriovenous difference across the muscle. Thus, to increase $\dot{V}o_2$ (or $\dot{V}O_{2max}$), muscle blood flow must increase (by increasing cardiac output) and/or the arteriovenous oxygen difference (aerobic enzymes and mitochondria) must increase.

DETERMINATION OF MAXIMAL AEROBIC CAPACITY

The level of $\dot{V}o_2$ attained during exercise is determined by the demand on the body (skeletal muscle). $\dot{V}O_{2max}$ can be determined for any volume of muscle by varying the mode of exercise, i.e. $\dot{V}O_{2max}$ for arms can be determined by using an arm crank test, or $\dot{V}O_{2max}$ of the calf muscle can be determined by performing repetitive ankle extension exercise. To determine $\dot{V}O_{2max}$, of the whole body, the demand placed on the body must be high enough to maximally burden the cardiovascular system (cardiac output and muscle blood flow capacity) and the muscle's metabolic capacity (mitochondria and aerobic enzymes). This is done by involving a large portion of the bodies muscle mass, generally by walking or running on a treadmill. In this case, demand is systematically incremented by increasing the speed and/or grade of the treadmill until the subject is unable to maintain the work.

A true $\dot{V}O_{2max}$ test can be defined as when three of the following four factors are achieved: a plateau in oxygen consumption with increasing work, a respiratory exchange ratio (RER) greater than 1.1, achievement of an age predicted maximum

heart rate (220-age), and a rating of perceived exertion of 19 or 20.

The maximal exercise test is considered a low risk procedure, approximately one fatality may occur in 25,000 tests and 2-4 nonfatal events in 10,000 tests in a hospital population (17). Morbidity and mortality are significantly less in a healthy, non-hospital populations and for submaximal exercise testing (17,56). Contraindications to exercise testing and indications for stopping the test may be found in *Guidelines for Exercise Testing and Prescription*, edited by the American College of Sports Medicine (1). The measurement of $\dot{V}O_{2max}$ is time consuming (preparation and administration usually require 1 hour) and requires a well equipped laboratory (gas analyzers, breathing valves, treadmills, gas volume meters, etc). Implementation of a $\dot{V}O_{2max}$ test requires at least two well-trained technical staff. Usually a physician, nurse or highly trained allied health professional is present to conduct the test (1).

FACTORS THAT AFFECT AEROBIC CAPACITY

MODE OF EXERCISE

In general, the mode of exercise testing can influence the actual numerical value obtained for $\dot{V}O_{2max}$, i.e. an arm cranking test will result in a lower numerical value compared to a treadmill test. $\dot{V}O_{2max}$ can be determined for any volume of muscle (thus, the difference in numerical value of $\dot{V}O_{2max}$) by varying the mode of exercise. The arm cranking test to determine $\dot{V}O_{2max}$ recruits a much smaller muscle volume, causing a smaller

numerical value, but still generates the $\dot{V}O_{2max}$ for that system. To determine $\dot{V}O_{2max}$, of the whole body, the demand placed on the body must be high enough to maximally burden the cardiovascular system (cardiac output and muscle blood flow capacity) and the muscle's metabolic capacity (mitochondria and aerobic enzymes). This is done by involving a large portion of the bodies muscle mass, generally by walking or running on a treadmill, or by cycling for those who are accustomed to cycling. In Europe and Scandinavia, where cycling is common, cycle testing is preferred to treadmill testing. In the United States, where cycling is not common, $\dot{V}O_{2max}$ from cycle ergometer testing is 10-25% lower than compared to treadmill $\dot{V}O_{2max}$ values (54). The reason for the lower value for $\dot{V}O_{2max}$ determined on the cycle ergometer is that the thigh muscles (quadriceps) fatigue prior to reacing a true $\dot{V}O_{2max}$.

Thus, state of training of an individual plays a role in modality. For example previously sedentary persons who trained for 20 weeks on a stationary cycle could perform equally as well on a cycle or a treadmill (54). Therefore, in North America the treadmill mode of testing is considered the standard, as the highest numerical values of $\dot{V}O_{2max}$ are usually achieved with this modality as it is more conducive to untrained subjects (57).

STATE OF TRAINING

Someone who regularly trains to increase aerobic capacity, i.e. endurance training, will have a 15-30% higher $\dot{V}O_{2max}$ than untrained individuals (56). In highly trained strength/power

athletes, $\dot{V}O_{2max}$ will be higher than untrained individuals but less than endurance trained individuals. Aerobic training increases exercise cardiac output by increasing stroke volume as maximal heart rate remains about the same, regardless of training. Thus, the amount of oxygen delivered and the amount utilized by working muscles increases, accounting for the increase in $\dot{V}O_{2max}$ due to training.

GENDER

The aerobic capacity for females is about 15-30% lower than for males (76). Males are generally able to generate more aerobic energy simply because of more muscle mass and less fat than the female counterpart. However males and females appear to adapt equally to training (53,55). Also men have a larger heart which facilitates a greater stroke volume and ultimately, cardiac output.

ALTITUDE

In general, the reduction in barometric pressure experienced during exposure to altitude decreases the driving pressure for oxygen, reduces hemoglobin oxygen saturation, and results in hypoxia. Thus, hypoxia is a relative lack of oxygen. Ultimately, hypoxia limits $\dot{V}O_{2max}$. Overall for each 300 meters increase in altitude, above 3000 meters, a 3.0% decline in $\dot{V}O_{2max}$ is seen (24). Below approximately 3000 m (~9000 ft.), $\dot{V}O_{2max}$ is unaffected by altitude (40). There may be a problem in estimating $\dot{V}O_{2max}$ from a submaximal steady state heart rate at altitudes of 1500-3000 meters because submaximal heart rate is

increased at these levels to increase $\dot{Q}$ and compensatory for reduced $[O_2]_a$.

AGE

Maximal aerobic capacity declines approximately 10% per decade for sedentary people, and 5% or less per decade for people who exercise regularly. Thus, there is an interaction between physical activity and aging which affects $\dot{V}O_{2max}$ (48).

HEREDITY

It has been estimated that between 40-70% of an individuals $\dot{V}O_{2max}$ is genetically determined (9). Body structure, muscle fiber type, and body composition are influenced by genetics and would have a direct effect on aerobic performance.

BODY COMPOSITION

Skeletal muscle (lean body mass) is responsible for utilizing oxygen to produce chemical energy which is concerted to mechanical energy to produce motion. Thus, skeletal muscle mass is a major determinant of $\dot{V}O_{2max}$. The ultimate level of $\dot{V}O_{2max}$ is related to the trained state of skeletal muscle. Muscle trained aerobically will elicit greater $\dot{V}O_{2max}$. Likewise, individuals with higher levels of body fat tend to have lower levels of lean muscle mass and therefore lower $\dot{V}O_{2max}$. Because body mass or body weight is a significant factor in aerobic performance, $\dot{V}O_{2max}$ is usually expressed in milliliters of oxygen per kilogram of body weight per minute ($ml \cdot kg^{-1} \cdot min^{-1}$).

ANEMIA

Anemia is a condition in which hemoglobin concentration is

low (< 13 g/dl for males and < 12 g/dl for females). The resulting loss of oxygen carrying capacity of the blood will decrease $\dot{V}O_{2max}$.

REPRODUCIBILITY AND VALIDITY OF VO2 MAX

Although the treadmill test and measurement of $\dot{V}O_{2max}$ is the gold standard used to determine aerobic capacity, it still has a day to day variation of 2-5% (1-3 $ml \cdot kg^{-1} \cdot min^{-1}$) (4,5,50,59). This may be due to the difficulty in achieving a plateau in oxygen consumption at maximal work loads as discussed earlier. There may also be day to day variations in work capacity related to diurnal variation of hormones, foods eaten, psychological moods, etc. Coefficients of variation ranging form 0.6-11.1% have been reported (7,20,27,85). Under less than ideal conditions, subjects exposed to short stress periods of exercise and/or heat exposure, acute starvation, bed rest, etc., can lead to greater day to day variation in $\dot{V}O_{2max}$ (72).

FIELD TESTS TO ESTIMATE AEROBIC CAPACITY

MAXIMAL FIELD TESTS

Field tests include cycle ergometer, endurance run tests, and walk tests. Storer, et al. (70) devised a cycle ergometer test in which 231 male and female subjects (ages 20-70) were taken to maximal power output without actually measuring $\dot{V}O_{2max}$. This eliminated predicting maximal power output, which is commonly done to aid in prediction of $\dot{V}O_{2max}$ and resulted in very high correlation ($r = 0.97$) and small error (SEE= 2.6 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to actual $\dot{V}O_{2max}$. However, this test is an actual

maximal test and is subject to the same drawbacks discussed previously.

Endurance run tests are based on the assumption that to move the human body, under its own power, a certain distance in a certain time, requires a reasonable amount of aerobic fitness. Balke (8) designed an endurance run in 1959 to test "fitness". The original study protocol was to run as fast as possible in 15 minutes (8), but was later modified by Cooper to a 12 minute run (14). Cooper's original data showed a correlation of r = 0.90 between estimated and measured $\dot{V}O_{2max}$. Subsequent studies on different populations, however, did not yield as high a correlation (r = 0.70), SEE = 5 $ml \cdot kg^{-1} \cdot min^{-1}$ (35,44,45).

A walk test used to estimate $\dot{V}O_{2max}$ was designed by Kline, et al. (37). An equation was developed to estimate $\dot{V}O_{2max}$ from weight, age, sex, heart rate and total time on a timed one mile track walk, during which subjects were asked to "walk as fast as possible". Subsequent analysis of the equation on 169 people yielded an r = 0.80 and SEE of 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$.

SUBMAXIMAL TESTING TO ESTIMATE AEROBIC CAPACITY

Because of the factors mentioned previously, it is too time consuming and costly to conduct treadmill tests to measure $\dot{V}O_{2max}$ in large populations of people. Field max tests are much more dangerous than lab max tests and appear to be less accurate. Thus, scientists have developed acceptably accurate, reproducible, easily measured and time efficient submaximal exercise tests that can estimate $\dot{V}O_{2max}$. These tests can be

conducted with easily portable equipment, such as a cycle ergometer or bench, and thus facilitate testing in laboratory or non-laboratory, field settings.

Often the estimation of $\dot{V}O_{2max}$ from a submaximal exercise test relies on the assumed linearity between heart rate and oxygen consumption during incremental power output tests. Stroke volume plateaus at approximately 40-50% of $\dot{V}O_{2max}$ and thus heart rate is the main component of increased cardiac output between 50% and 100% of maximum exercise (24). It is this linearity between heart rate and oxygen consumption and also the ease of measurement of heart rate that makes it a commonly used variable to predict $\dot{V}O_{2max}$. Heart rate at rest and submaximal exercise is lower in physically fit personnel, while maximal heart rate is independent of training status. Thus, the lower heart rate in fit individuals at a given submaximal workload will extrapolate to a higher $\dot{V}O_{2max}$.

The accuracy of estimating $\dot{V}O_{2max}$ from submaximal heart rate is based on four assumptions.

1. The linearity of heart rate-oxygen consumption relationship is constant.
2. Similar maximal heart rates are found for individuals of the same age.
3. All persons have a similar exercise economy or mechanical efficiency.
4. Submaximal heart rates do not vary from day to day.

The first assumption is met at 10-85% of $\dot{V}O_{2max}$, as discussed

previously, but towards maximal effort heart rate often peaks prior to $\dot{V}O_{2max}$.

The second assumption is not always met. In actuality, maximal heart rate has a standard deviation of ±12 beats/min (48). If we assume two standard deviation units, the variation in maximal heart rate is ±25 beats/min., based on a predicted maximal heart rate of 220-age. This variation in heart rate can cause a significant under- or over-estimation of $\dot{V}O_{2max}$ using heart rate/oxygen extrapolation methods.

In the third assumption, the variation of individuals in oxygen consumption due to technique or mechanics when using different ergometers is approximately ±6%, which may also cause under- or over-estimations of $\dot{V}O_{2max}$ (48).

The fourth assumption is also not always met, because even under highly standardized conditions, variation of heart rate day to day during the same submaximal power output can be as high as ±5 beats/min. (66). Submaximal heart rate can be influenced by time of day (morning vs. afternoon), smoking, eating, caffeine ingestion, rest/sleep, illness, heat, humidity, fatigue, stress, hydration status, and psychological status.

Submaximal estimation of $\dot{V}O_{2max}$ from heart rate is accurate within 10-20% of a person's actual value (48). This variation may be unacceptable for many applications, however, this technique is well-suited for screening and classifying large numbers of individuals in terms of aerobic fitness.

ASTRAND-RHYMING NOMOGRAM

In 1954, Astrand and Rhyming developed a nomogram which estimated $\dot{V}O_{2max}$ from a submaximal power output (6). It was based on their findings that the relationship between heart rate and $\dot{V}o_2$ was linear. Submaximal work included bench stepping, cycle ergometry, and running on a treadmill. The original study used 27 male and 31 female subjects ages 20-30 years. A nomogram was developed using heart rate and work level from a submaximal power output, and body weight, to estimate $\dot{V}O_{2max}$. The subject exercised for 5-6 minutes at a steady state power output. The "best predicting results" were seen when the workload elicited a heart rate between 125-170 beats/min. With this nomogram, the $\dot{V}O_{2max}$ could simply be extrapolated.

The Astrand-Rhyming nomogram was modified for a cycle ergometer exercise only and used in a study with a greater number of subjects (n=144) (3). Data from both studies (3,6) were used to modify and improve the nomogram. An age correction factor was also introduced in this same study (3).

Later, von Dobeln et al. introduced slightly different age correction factors (77), which were subsequently found to slightly underestimate measured $\dot{V}O_{2max}$ (13).

In 1966, Teraslinna et al. developed a coefficient (73) in which the correlation between $\dot{V}O_{2max}$ and estimated $\dot{V}O_{2max}$ was $r = 0.69$. When corrected for age the correlation was 0.92. Glassford, et al. (22), also calculated a validity coefficient of 0.80 for the nomogram using 24 healthy male students.

Subsequent testing of the original Astrand-Rhyming nomogram has yielded more modifications (66), and varying correlations (10,15,16,23,27,32,52,55,69,74,81,83,84) ranging from $r = 0.39$ to $r = 0.94$ with SEE of 3.3 to 10.7 $ml \cdot kg^{-1} \cdot min^{-1}$. See Table 1 for a summary of these studies.

OTHER SUBMAXIMAL TESTING PROTOCOLS TO ESTIMATE AEROBIC CAPACITY

Many protocols to predict $\dot{V}O_{2max}$ have been developed before and since the Astrand-Rhyming test. Indeed, predating Astrand-Rhyming by a number of years was the Sjostrand-Wahlund test (68,78). This cycle ergometer test was the precursor to the modern YMCA test in that it used multiple stages: a 3 minute warmup stage and two 3 minute stages (identical to the current YMCA test).

Other tests to predict $\dot{V}O_{2max}$ include protocols by Margaria et al. (47), Fox et al. (19), Verma et al. (75), Fitchett et al. (18), and Sady et al. (60), and still other tests have been devised to predict $\dot{V}O_{2max}$ from timed endurance runs (36).

SUBMAXIMAL TESTING BY THE AIR FORCE

The U.S. Air Force (USAF) has been using a 12 minute or 1.5 mile timed run to estimate aerobic fitness since 1970. In 1991, Sharp suggested an "interview by practitioner" may help to eliminate those "at risk" for the 1.5 mile field run (63). This was due to anecdotal evidence that there had been deaths associated with the timed run (79). Indeed, qualification times were progressively increased and candidates for the USAF had the choice of walking 3 miles in the interest of "safety" and

motivation.

More recently, the USAF has developed a submaximal cycle ergometer (SCE) test to estimate $\dot{V}O_{2max}$. This test is a modification of the Astrand-Rhyming cycle ergometer test in which power output is increased each minute as needed using a computer algorithm that sets workload (power output) to elicit a steady state heart rate. The computer program then estimates $\dot{V}O_{2max}$ from the final power output, height, weight, gender, steady state heart rate, and an age correction factor (see methods). Using 22 fit and nonfit males, Hartung et al. (29) reported a correlation of 0.95 between the estimated and measured $\dot{V}o_2$, with a standard error of the estimate (SEE) of 4.25 $ml \cdot kg^{-1} \cdot min^{-1}$, although this method underpredicts treadmill measured $\dot{V}O_{2max}$ by about 20%. Unpublished data (82) using the same protocol with 50 male USAF officers resulted in an r of 0.74 and a 17% underprediction of $\dot{V}O_{2max}$.

Table 1 summarizes the results from 33 studies which use maximal and submaximal field tests and submaximal laboratory tests to estimate $\dot{V}O_{2max}$. It includes authors, style or type of work, r values, number of subjects, ages, etc. Reproducibility of the tests was not addressed by most studies and hence has been excluded from the table. The gold standard for determination of $\dot{V}O_{2max}$ is a maximal treadmill or cycle ergometry laboratory test, which has high reproducibility (r= 0.95 to 0.98) and small error (SEE= 1-3 $ml \cdot kg^{-1} \cdot min^{-1}$). The next hierarchy of tests would be the maximal treadmill or cycle ergometer tests without actual

TABLE 1: **A SUMMARY OF ESTIMATIONS OF VO2 MAX**

				SUBMAXIMAL TESTING ESTIMATIONS		
PRIMARY AUTHOR (REF. #)	N	AGES (range in years)	SEX	TYPE	R	SEE in ml/kg/min (SEE %)
Arts (9)	22	mean=27.2	m	cycle w/prediction equation	*	* (*)
Astrand (6)	31 28	20-30 20-30	f m	Astrand-Rhyming cycle protocol	*	* (*)
Cink (13)	40	18-33	m	Astrand-Rhyming cycle protocol Astrand-Rhyming cycle protocol w/von Dobeln age correction factor	0.83 0.84	5.7 ml (*) 5.5 ml (*)
Davies (15)	80	20-50	m	Astrand-Rhyming cycle protocol Margaria cycle protocol Maritz-Wyndham cycle protocol	*	* (15%)
deVries (16)	16	20-26	m	Sjostrand-cycle Sjostrand-bench Harvard step test Progressive Pulse Ratio (step) Delta R.Q. (cycle) Astrand-Rhyming cycle protocol	0.87 0.20 0.77 0.71 0.33 0.74	4.7 ml (9%) * (*) 6.4 ml (13%) 6.9 ml (14%) * (*) 4.8 ml (9%)
Fitchett (18)	12	23-58	m	step-progressive step-steady-state cycle-progressive cycle steady-state	0.72 0.66 0.67 0.84	* (16%) * (13%) * (13%) * (9%)
Fox (19)	87	17-27	m	cycle w/prediction equation	0.76	3.3 ml (8%)
Glassford (22)	24	17-33	m	Astrand-Rhyming cycle protocol	0.80	10.7 ml (*)

Harrison (27)	9	22-41	m	Astrand-Rhyming cycle protocol Margaria step treadmill walk w/prediction equation 2 km run w/prediction equation	0.82 0.91 0.66 0.92	* (*) * (12%) * (*) * (12%)
Hartung (29)	22	mean=36.5	m	cycle w/prediction equation (USAF)	0.95	4.3 ml (*)
Jessup (32)	60	18-23	m	Astrand-Rhyming cycle protocol	0.65	4.1 ml (9%)
Jette (33)	35 29	20-54	m f	Canadian Home Fitness Test (step) Astrand-Rhyming cycle protocol	0.71 0.47	4.2 ml (12%) 5.3 ml (15%)
Kasch (34)	83	30-70	m	Astrand-Rhyming cycle protocol Sjostrand cycle	0.58 0.55	6.2 ml (*) 4.7 ml (*)
Latin (38)	28 25	29-41 29-41	m f	Treadmill walk Treadmill run (Astrand-Rhyming protocol w/ACSM guidelines)	0.82 0.86	6.3 ml (15%) 7.1 ml (13%)
Louhevaara (43)	22	29-41	m	Astrand-Rhyming protocol (HighWork Load) Astrand-Rhyming protocol (LowWorkLoad) 2 pt. extrapolation World Health Org. 3 pt. extrapolation World Health Org.	0.39 0.73 0.83 0.81	7.3 ml (*) 7.2 ml (*) 4.8 ml (*) 4.7 ml (*)
Margaria (47)	44 18	9-47	m f	benchstep w/ prediction equation	*	* (7%)
Oja (52)	48	29-37	m/f	Astrand-Rhyming protocol (cycle) von Dobeln protocol (cycle)	0.54 0.66	5.6 ml (*) 4.8 ml (*)
Rowell (59)	22	18-24	m	Astrand-Rhyming cycle protocol	0.64	7.4 ml (*)
Sady (60)	40	22-37	f preg.	Astrand-Rhyming cycle protocol VO2 - Heart-rate extrapolation	0.77 0.85	* (10.4%) * (8.7%)
Sarelius (62)	61 33	14-37	m f	Astrand-Rhyming cycle protocol von Dobeln (cycle) VO2-Heart-rate extrapolation (cycle)	*	* (*)

Shvartz (65)	44	17-19	m	Kilometer run w/prediction equation	-0.34	* (*)
Siconolfini (66)	113	20-70	m/f	modified Astrand-Rhyming cycle protocol	0.94	3.3 ml (*)
Terry (74)	60	18-23	m	Astrand-Rhyming cycle protocol	0.65	4.1 ml (9%)
Teraslinna (73)	31	23-49	m	Astrand-Rhyming cycle protocol Astrand-Rhyming cycle protocol corrected for age	0.69 0.92	5.3 ml (*) * (*)
Verma (75)	45	19-31	m/f	cycle w/prediction equation	0.81	* (*)
von Debeln (77)	84	30-70	m	cycle w/prediction equation	*	* (13%)
Weller (80)	129	15-69	m/f	Canadian Home Fitness Test (step)	0.75	* (*)
Williams (81)	31	*	f	Astrand-Rhyming cycle protocol	0.64	* (*)
				FIELD/MAX TESTING ESTIMATIONS		
PRIMARY AUTHOR (REF. #)	N	AGES (range in years)	SEX	TYPE	R	SEE in ml/kg/min (SEE %)
Balke (8)	455	22-65	m	treadmill test w/prediction equation	*	* (*)
Cooper (14)	115	17-52	m	12 min field run	0.90	* (*)
Kline (37)	165 178	30-69 30-69	m f	1 mile walk w/prediction equation	0.92	4.7 ml (*)
Ramsbottom (58)	36 38	19-36	m f	20m progressive shuttle run	0.92	* (*)
Storer (70)	115 116	20-70 20-70	m f	cycle w/prediction equation	0.94 0.95	2.6 ml (*) 2.3 ml (*)

* denotes data missing from study
m = males
f = females

determination of $\dot{V}O_2$. The $\dot{V}O_{2max}$ is estimated by treadmill time or maximal power output. These tests generally correlate highly with actual $\dot{V}O_{2max}$ (r= 0.90 - 0.95) with a small error (SEE= 3-5 $ml \cdot kg^{-1} \cdot min^{-1}$). Maximal field tests (Cooper 12 min and 1.5 mile runs, etc.) report high correlations (r= 0.85 - 0.90), and small error (SEE= 4-6 $ml \cdot kg^{-1} \cdot min^{-1}$) with laboratory treadmill $\dot{V}O_{2max}$ tests, but have the drawback of higher risk and problems with subject motivation. Submaximal field tests used to estimate $\dot{V}O_{2max}$, in general, appear to be less predictive (r= 0.20 - 0.90), with a greater error (SEE= 2-11 $ml \cdot kg^{-1} \cdot min^{-1}$). Submaximal step tests have not had good correlations because of variability (range of r= 0.20 - 0.91), and error (SEE= 4.7 - 6.4 $ml \cdot kg^{-1} \cdot min^{-1}$). Submaximal treadmill or cycle ergometry tests have higher correlations than step tests (range of r= 0.66 - 0.92, SEE= 4.1 - 10.7 $ml \cdot kg^{-1} \cdot min^{-1}$). Therefore, modality is a key issue when choosing a submaximal test to estimate $\dot{V}O_{2max}$. Given the high correlation between $\dot{V}O_{2max}$ determined from laboratory maximal tests and submaximal treadmill and cycle ergometry estimations, there is no apparent advantage to using maximal laboratory or field tests to estimate $\dot{V}O_{2max}$ over submaximal treadmill and cycle ergometry tests.

SHORTCOMINGS OF PREDICTION OF $\dot{V}O_{2max}$ FROM SUBMAXIMAL ERGOMETRY

It appears that the major shortcomings of submaximal exercise tests used to predict $\dot{V}O_{2max}$ was their inconsistency in deriving adequate correlations in many studies and a lack of reproducibility. However, submaximal predictions of $\dot{V}O_{2max}$, even

with an error of 10-20% (4-10 $ml \cdot kg^{-1} \cdot min^{-1}$), make excellent field tests as long as they are not used as clinical data. There are a number of other factors that can effect heart rate and ventilation, which may have a profound influence on predictions of $\dot{V}O_{2max}$. These are pedaling frequency, seat height, circadian rhythms, caffeine, warming up, and smoking.

PEDALING FREQUENCY

Pedaling frequency on cycle ergometer has been shown to affect the relationship between caloric output and work rate. Using delta efficiency measurements, Gaesser and Brooks found that 60 rpm pedal frequency was the most efficient (21). This paper did not report whether the subjects were cyclists but all subjects were "well-trained". A subsequent study (25) on trained cyclists riding their road cycles showed the most economical pedaling rate at 91 rpm, most likely due to their training at higher pedaling frequency. Direct effects of pedaling frequency on $\dot{V}o_2$ are equivocal. Studies show that $\dot{V}o_2$ is unchanged (42) or increases (49) with different pedaling frequencies. Other studies show that 60 rpm is optimal for $\dot{V}O_{2max}$ (26,30). Thus, pedaling frequency may have possible effects on estimations of $\dot{V}O_{2max}$ but more data are needed.

Evidence (48) indicates that heart rate appears to be unaffected by pedaling frequency. In general, due to the largely untrained nature of the subjects in this experiment, it is important to pick a pedaling frequency that will be comfortable for untrained and older subjects, and thus a pedaling rate

between 40 and 70 rpm appears satisfactory.

SEAT HEIGHT

Due to the individual differnces in leg lengths, the ergometer seat height must be properly adjusted to optimize efficiency. Inappropriate adjustment of seat height can alter $\dot{V}O_{2max}$ (51).

CIRCADIAN RHYTHMS

Time of day variation in body temperature, heart rate, etc., may possibly effect response to submaximal exercise. However, two studies have reported no difference due to time of day in $\dot{V}O_{2max}$ prediction or heart rate response to cycle ergometry (15,31).

CAFFEINE

Caffeine ingestion increases heart rate, has a vasodilatory effect peripherally and a vasoconstrictive effect centrally (11). The increased heart rate seems to be of short duration (44); yet, it is obvious that caffeine intake prior to SCE will increase heart rate and thus skew heart rate-$\dot{V}o_2$ prediction equations. The impact of caffeine ingestion and $\dot{V}O_{2max}$ prediction has not been studied.

WARMING UP

Most reports indicate that warming up fails to produce any favorable influence on $\dot{V}o_2$ at submaximal or maximal power output (12). The early stages of many maximal protocols, e.g. the Bruce test, have a "warm-up" built into the protocol as the first stage is a very light work load.

SMOKING

Cigarette smoking is associated with lower $beta_2$-adrenoceptor density compared to non-smokers (39). An adrenergic receptor is present on cell membranes of target organs i.e. the heart. A decrease in density of $beta_2$-adrenergic receptors would result in a decrease in heart rate in response to cardiovascular stress such as exercise. Chronic smoking appears to blunt the heart rate response to exercise, which would result in overpredictions of $\dot{V}O_{2max}$ in submaximal test prediction protocols (67).

CONCLUSIONS

$\dot{V}O_{2max}$ is the primary criteria for determining aerobic endurance work capacity. To increase $\dot{V}O_{2max}$, increased muscle oxygen delivery or increased muscle tissue oxygen extraction, or a combination of the two, must occur. The laboratory maximal treadmill testing is the gold standard for determining $\dot{V}O_{2max}$. An accurate and reproducible method of estimating $\dot{V}O_{2max}$ at submaximal levels is desirable due to the high cost, time expenditure, and safety of conducting actual $\dot{V}O_{2max}$ tests in the laboratory or maximal field testing in large populations. Treadmill or cycle ergometer tests which estimate $\dot{V}O_{2max}$ from exercise time or maximal power output correlate highly with actual $\dot{V}O_{2max}$ ($r= 0.90 - 0.95$, SEE= 3-5 $ml \cdot kg^{-1} \cdot min^{-1}$). Maximal field tests, such as the Cooper 12 min run or 1.5 mile run, correlate highly with actual $\dot{V}O_{2max}$ ($r= 0.85-0.90$, SEE= 4-6 $ml \cdot kg^{-1} \cdot min^{-1}$). When using submaximal tests to estimate $\dot{V}O_{2max}$,

correlation of the estimate with the actual $\dot{V}O_{2max}$ depends on choice of modality. Submaximal cycle ergometry tests correlate very well with actual $\dot{V}O_{2max}$ (r= 0.70-0.85, SEE= 5-7 $ml \cdot kg^{-1} \cdot min^{-1}$). When using submaximal cycle ergometry to estimate $\dot{V}O_{2max}$, a number of factors that effect heart rate must be controlled for: age, gender, circadian heart rhythm, smoking, caffeine, pedaling frequency, and seat height.

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Methods

Initial Screening and Visit 1 Testing

Two hundred and seven male (N=103) and female (N=104) volunteers between the ages of 18 and 54 yr participated in this study. Subjects were recruited by newspaper ads and posted fliers. The subject pool included University of Florida (UF) student body and staff, as well as residents from the Gainesville, FL and surrounding communities. The project was approved by the Institutional Review Board of the Department of Medicine, UF College of Medicine.

Subjects were screened over the telephone and invited to the UF Center for Exercise Science for their initial visit. Exclusion criteria for entrance into the study were: cardiovascular and pulmonary diseases, hypertension, orthopaedic limitations to exercise, pregnancy, blood donation within 15 days of the first visit, use of beta-blocker drugs or beta-agonist asthma medication, and the inability to complete all tests within 3-4 weeks. Prior to each testing session, subjects were asked to abstain from caffeine or tobacco products for a minimum of 4 hours; food for 3 hours; and any alcohol consumption, strenuous exercise or exertion for 10 hours. To help verify these standardized conditions subjects were asked to complete a 24 hour health history and activity questionnaire (Appendix A). Initially, all subjects falling outside of the U.S. Air Force

(USAF) height and weight standards were excluded (Appendix B). As it became clear that the height and weight guidelines were too stringent for the recruitment of subjects into the low fitness categories, these standards were relaxed. As a gauge of the number of subjects that would have been excluded from the study by this standard alone, a normative study conducted by the Cooper Clinic, Dallas TX, showed that approximately 40% of the males and females who were classified as low fit by the USAF study guidelines that will be described later, would have been classified as obese (1). Testing was rescheduled for any subject who had violated any of the above mentioned guidelines for test standardization or who did not feel well as described in the 24-hour health history questionnaire.

Subjects were given an explanation of the proposed project and then asked to read and sign an informed consent form, and complete medical history and physical activity questionnaires (Appendix C,D,E). The subjects were dressed in light exercise gear and were asked to take their shoes off for the measurement of height and weight. Height was measured to the nearest 0.1 cm with a wall mounted Harpenden stadiometer (model 602, Holtain, Ltd., England) and weight to the nearest 100g with a Detecto Scale (model 8430, Webb City, MO). From the height and weight measures body mass index was determined (BMI = Wt(kg) / $ht^2(m^2)$). Spirometry to determine forced vital capacity (FVC) and forced expiratory volume during the first second of expiration (FEV1) was conducted to screen for pulmonary limitations. A Medical

Graphics CAD/NET System 1070 (Medical Graphics, St. Paul, MN) was used for pulmonary screening. The FEV1/ FVC ratio is especially sensitive to pathological changes in lung function, such as the increased resistance to flow seen in asthmatics (2). A FEV1/FVC ratio of about 80% is considered normal (2). Subjects with a FEV1/FVC ratio below 70% were excluded from the study.

Subjects then received an orientation to the testing facility, an explanation of testing procedures and a baseline submaximal cycle ergometry (SCE) test to estimate aerobic capacity ($\dot{V}O_{2max}$ $ml \cdot kg^{-1} \cdot min^{-1}$). The baseline screening SCE test was thought to typify the conditions of a first test situation used for USAF personnel. The USAF SCE test is a modification of the original Astrand-Rhyming protocol (13). All cycle ergometry was conducted using the Monark 818E cycle ergometer (Monark, Stockholm, Sweden). The cycle ergometer was calibrated once every morning and afternoon using the USAF field calibration method (Appendix F)(3). Minimal or no adjustment was needed at each calibration, suggesting that a relatively constant and stable resistance was maintained throughout all tests for a given resistance setting.

Seat height was adjusted to approximately 100% of heel to trochanter length and recorded for each subject using a method suggested by Nordeen-Snyder (4). This was accomplished by having the subject sit upright on the saddle with one heel on a pedal that was at the bottom of the pedal stroke. The seat was then adjusted so that the subject's leg was fully extended. Seat

height was kept constant for all tests. Pedaling cadence was also kept constant at 50 revolutions per minute (RPM) for all submaximal tests. Subjects were able to watch an LCD RPM gauge on the cycle ergometer and listen to a metronome set at 100 beats/min which coincided with each pedal stroke. Metronomes were calibrated before every test. The USAF prototype software was used for the baseline SCE test and the software logic for power output adjustment was followed. The starting power output was based on gender, age, weight, activity level and whether a subject was a smoker (Appendix G). According to USAF software, a subject was classified as active if he or she "participates in strenuous physical activity at least 2 times per week" (5).

The USAF SCE test is a 6 minute test. The test begins with a 3 minute adjustment period that attempts to regulate the power output to a level that elicits a steady state HR above 121 beats/min (see Appendix H for details of protocol progression). The software may recommend power output increases to be made after every minute of exercise during the first 3 minute adjustment period, based on HR and age (Appendix H). The final 6 minutes of the SCE test were conducted at a power output that was determined during the adjustment period. A seventh minute of cycling was added if the final two HR's (minutes 5 and 6) differed by more than ±3 beats/min. A test was considered invalid if the 7 minute HR was not within ±3 beats/min of the HR obtained for minute 5 or 6. A HR exceeding 85% of 220 - age

(estimation of maximum HR) was the most common reason a baseline test was labeled invalid. After the completion of each SCE test, a cool-down period occurred whereby the power output was reduced to 0.5 Kp and the subject was instructed to continue pedaling at a self selected cadence until his or her HR was below 100 beats/min. A second baseline SCE test was conducted on a subsequent visit if the initial baseline test was considered invalid.

Heart rate was monitored by a Polar Favor or Polar Pacer wireless HR monitor (Polar CIC, Port Washington, NY) and a four lead electrocardiogram (ECG) (II, AVF, V5; Quinton Q4000, Seattle, WA). Instruments were set up so that subjects were unable to observe their own HR during all SCE tests. HR's were recorded for the last 10 seconds of each minute of exercise. Power outputs for each minute of exercise were recorded. Also, total body and leg ratings of perceived exertion (RPE) were obtained during the final 10 seconds of every second minute of exercise during the final 6 minutes of each SCE test (Appendix I). The total body RPE is a number that the subject was asked to choose from a chart and reflects the subject's total amount of exertion and fatigue; combining all sensations and feelings of physical stress, effort and fatigue (Appendix J) (6). The leg RPE is similar to the total body RPE except that the subject was asked to focus solely on the above described feelings in his or her legs.

Based on the initial SCE test, subjects were classified

into low fit, medium fit or highly fit categories (Appendix K). A lot of effort was made to fill a subject matrix based on $\dot{V}O_{2max}$ $ml \cdot kg^{-1} \cdot min^{-1}$, gender and age. This matrix was described in the initial statement of work and modified on November 8, 1993 (Appendix K). Approximately 44 subjects were excluded from the study because they fell into filled or over-filled categories in this matrix. Subjects exhibiting abnormal ECG's were also excluded and referred to appropriate care givers. A minimum of 24 hours of rest was required after SCE tests and 72 hours after a maximal exertion test.

Visit 2:

Subjects reported to the laboratory to perform a maximal treadmill test during the second visit. As described earlier, subjects completed a 24 hour health history questionnaire and body weight was measured. As recommended by exercise testing guidelines set forth by the American College of Sports Medicine (ACSM), female subjects over the age of 50 yr and male subjects over the age of 40 yr received a pretest physical evaluation from a physician (Appendix L)(7). The physician also monitored the maximal treadmill test of these subjects.

The standard Bruce treadmill protocol was used for all subjects (Appendix M) (8). The purposes of this test were to determine actually measured maximal oxygen consumption (aerobic capacity, $\dot{V}O_{2max}$) and to serve as an additional screen for exercise contraindications to continue in the study. Pretest

blood pressures (BP) and ECG recordings were obtained. The ECG was monitored throughout the entire test and recovery period. The HR, RPE, cardiac rhythm and exercise induced changes of ECG recordings were made at 50 seconds of each minute of testing and recovery. Cardiac disrhythmias that occurred at other times were also recorded. Blood pressure was measured during exercise at 2:30 minutes of each stage, at peak exercise, immediately post exercise, and during a supine recovery at 1,3,5,7 minutes.

Expired oxygen (O2) and carbon dioxide (C02) gas concentrations and expiratory minute volumes (V_E) were collected and recorded to measure aerobic function. The Medical Graphics Cardiopulmonary Gas Analyzer CPX/MAX (Med Graphics, St. Paul, MN) was used to obtain breath by breath measurements of $\dot{V}O_2$. Additionally, during approximately the last 3 minutes of a test, all expired air was collected in Douglas bags. These are large latex balloons from which expired gas concentrations and V_E were obtained. Oxygen consumption and $\dot{V}O_{2max}$ were determined by calculating the fraction and volume of O_2 and CO_2 removed from the ambient air. The Douglas bag technique was used to reconfirm values obtained by the Med Graphics system and has been shown to be an accurate method to measure aerobic capacity (9). Treadmill speed and grade, test duration, end-minute HR's, end-minute RPE and environmental conditions (temperature, barometric pressure, and humidity) were recorded for each test.

Subjects were encouraged to continue walking or jogging as long as possible in order to obtain a true maximal effort and

hence a $\dot{V}O_{2max}$. A true $\dot{V}O_{2max}$ test was defined as when three of the following four factors were achieved: a plateau in oxygen consumption with increasing work, a respiratory exchange ratio (RER) greater than 1.1, achievement of an age predicted maximum HR (220-age), and an RPE of 19 or 20. A minimum of 72 hours of recovery time was allowed before further testing was conducted. Any subjects with an abnormal ECG or BP response, at rest, during the test or recovery, were excluded and referred to appropriate healthcare providers.

Visits 3-6:.

During visits three through six, four additional USAF SCE tests (SCE-1 through SCE-4) were performed. Two trials (SCE-1 and SCE-2) were performed following the logic defined by the USAF prototype software. Subjects reported to the laboratory and completed a 24-hour health history and activity questionnaire, and body weight was measured. All subjects over 40 years of age received a HR monitor transmitter and 4 lead electrode installation, as described previously. Subjects under the age of 40 only received a HR monitor transmitter installation. The purpose of this was to monitor heart rhythm in the older potentially higher cardiac risk population, as well as to track the accuracy of the Polar system with the hard wire ECG system.

The software recommended a power output setting to achieve a steady-state HR based upon the most recent SCE (baseline or SCE-1) test. Software logic was overridden when, by knowledge of

previous tests, it appeared that by following the subsequent software logic would cause an invalid test. Trials flagged as invalid by violations of computer logic or other test errors were repeated, on subsequent days, until two valid trials were obtained. Violations (invalid test) included a HR in excess of 85% of 220-age, a HR change >±3 beats during the last two minutes of an SCE, or a subject's inability to continue exercise due to excessive leg fatigue (power output). The other test errors were primarily due to the inability to measure HR accurately. This occurred because of improper HR monitor transmitter installation on the subject or HR monitor transmitter failure. Additionally, if the end-of-test power output in trials 1 and 2 differed, a third trial (SCE-2a) was performed to obtain a steady state HR for two tests that were performed at the same end-of-test power output.

The remaining two trials (SCE-3 and SCE-4) were completed using a starting power output that was 0.5 KP higher or 0.5 KP lower than the power output achieved in trials 1 and 2. As outlined by the statement of work, if the average steady state HR (average HR over the final 2 minutes of the SCE) for SCE-1 and SCE-2 was less than 0.72 of the maximum treadmill HR, the starting power output for the final two trials was set 0.5 KP higher than during SCE-1 and SCE-2. If the average steady state HR at the power output used in SCE-1 or SCE-2 was greater than 0.72 of the treadmill maximum HR, the power output for SCE-3 and SCE-4 was set 0.5 KP lower. Power output was not adjusted after

starting the test during SCE-3 and SCE-4. If steady state HR was not achieved by 6-7 minutes of cycling, the results were considered invalid for subsequent data analysis. Invalid tests were repeated.

During one of the visits (3-6) an estimation of body composition was determined using the seven site skinfold method of Jackson and Pollock (1). For the seven site skinfold technique, measurements of skinfold thickness using the Lange Skinfold caliper (Cambridge Instruments, Cambridge, MD) were made at the chest, axilla, subscapular, triceps, suprailium, abdomen, and anterior thigh. The sum of these seven measurements, weight, gender and age were used in the Jackson-Pollock equation to obtain a subject's body density (1). The body density value was used to calculate percent fat, fat mass and fat free mass.

Visit 7:

Subjects reported to the laboratory to perform a maximal cycle ergometer test during their seventh visit. The purpose of the test was to compare the cycle ergometer maximal test results with the maximal treadmill test and the SCE estimations of $\dot{V}O_{2max}$. It was important to determine whether the USAF SCE test estimates $\dot{V}O_{2max}$ better compared to a maximal cycle ergometer or treadmill test $\dot{V}O_{2max}$. Usually for persons who are not accustomed to cycle riding, there is a 10-25% lower $\dot{V}O_{2max}$ value attained during cycle versus treadmill testing. Subjects were hooked up to a 4 lead electrode preparation, as described for Visit 1. A modified

Astrand-Saltin maximal cycle protocol was used for all subjects to determine $\dot{V}O_{2max}$ (11). The test required subjects to cycle at a fixed cadence of 60 RPM with power output being increased every 2 minutes until the subject could no longer maintain cadence (Appendix N). Men began the test at 360 kpm/min and resistance was increased by 360 kpm/min per stage until exhaustion. Females also began at 360 kpm/min but, resistance was increased by 180 kpm/min per stage, until exhaustion. As during the maximal treadmill tests, subjects were encouraged to give a maximal effort. Data collection and maximal test criteria were identical to those of the maximal treadmill test (Visit 2). A minimum of 72 hours of recovery was required before the final visit was conducted.

Visit 8:

A YMCA SCE test was conducted during the final visit. The protocol followed is outlined in The Y's Way to Physical Fitness (12). Like the USAF SCE test, the YMCA test is a modification of the Astrand-Rhyming submaximal cycle test (13). Subjects were also required to maintain a cadence of 50 RPM throughout the test and were paced by a metronome set at a 100 beats/min and the tachometer accompanying the Monark cycle ergometer. Each subject began exercise at 150 kpm/min and power output progression was based on the subject's HR response to this first stage of exercise (Appendix O).

Each stage of the YMCA test lasted 3 minutes. If a

subject's HR varied >5 beats/min between the last 2 minutes of each stage, an additional minute was added to that stage. This was continued until HR's for the last two minutes of a stage were within ± 5 beats per minute. A test was considered invalid, and repeated on a subsequent visit, if a subject's HR did not plateau or the subject could no longer maintain cadence. The test was designed to be a 3 stage test: the 150 kpm/min warmup stage and two additional submaximal exercise stages from which the aerobic capacity was calculated. The test assumes that the linear relationship between HR and $\dot{V}O_{2max}$ does not occur until the HR is greater than 110 beats per/min (12). Therefore, a fourth exercise stage was added if a subjects' HR did not exceed 110 beats/min for both of the final stages.

Subject preparation and data collection were also identical to that of the USAF SCE tests. Overall and leg RPE's were obtained at 50 seconds of the last minute of every stage. Power output increases were made during the last 10 seconds of the last minute of every stage. Instead of using the nomogram supplied by <u>The Y's Way to Physical Fitness</u>, aerobic capacity was calculated using the equation included in the Health Check software (Tucson, AZ). This software is derived from the original prediction equation from <u>The Y's Way to Physical Fitness</u> (11).

Data Analysis:

A total of 207 subjects participated in this study. Since not all of them completed all eight visits, the subjects were

divided into three groups or phases: Phase I (n=134), subjects who completed the first four visits (baseline SCE, treadmill VO_{2max} test, SCE-1, and SCE-2); Phase II (n=113), subjects who completed the first seven visits (Phase I plus SCE-3, SCE-4, and the cycle VO_{2max} test); and Phase III (n=102), subjects who completed all eight visits (phases I and II plus the YMCA SCE). Cross-validation statistics (mean differences, Pearson correlation coefficients (r), standard errors of the estimate (SEE), %SEE, and total errors (E) were performed on all three phases in two ways: One both males and females combined, and two, sorted by gender (Phase 1: n_{males}=67, $n_{females}$=67; Phase II: n_{males}=58, $n_{females}$=55; and Phase III: n_{males}=55, $n_{females}$=47). In addition, for the Phase I group only, cross-validation statistics were calculated for the following classifications: One, High-Fit (n=85) vs Low-Fit (n=49); two, Younger Adults (n=68) vs Older Adults (n=66); and three, Cyclists (n=26) vs Non-Cyclists (n=108). High-Fit subjects were defined as having a USAF Fitness Category of 4, 5, or 6 while the Low-Fit subjects fell into categories 1, 2, or 3. (See Appendix P for details of the USAF Fitness Categories.) The Younger Adults ranged in age from 19-39 yrs while the Older Adults were between the ages of 40 and 54 yrs. Subjects who reported to be triathletes, both runners and cyclists, or pure cyclists were grouped into the Cyclist classification while all others (active or sedentary) were placed in the Non-Cyclist group. These three classifications were also analyzed as whole groups and sorted by gender (High-Fit: n_{males}=48,

$n_{females}$=37; Low-Fit: n_{males}=19, $n_{females}$=30; Younger Adults: n_{males}=35, $n_{females}$=33; Older Adults: n_{males}=32, $n_{females}$=34; Cyclists: n_{males}=19, $n_{females}$=7; Non-Cyclists: n_{males}=48, $n_{females}$=60).

Cross-Validation Statistics:

The cross-validation procedures recommended by Lohman (13) were used to determine whether the aerobic capacities obtained from the SCE tests (baseline SCE, SCE-1 through SCE-4, and the YMCA test) accurately predicted the criterion aerobic capacities (treadmill VO_{2max} and, when applicable, cycle VO_{2max}). This involved calculating mean differences, Pearson correlation coefficients (r), standard errors of the estimate (SEE), %SEE, and total errors (E).

Mean Difference:

The mean difference was calculated as follows: mean criterion aerobic capacity - mean SCE aerobic capacity (treadmill or cycle VO_{2max}), (baseline. SCE, SCE-1 to SCE-4, or YMCA). The more similar these two means were, the closer the mean difference was to zero, and therefore, the better the prediction. Also, a positive mean difference indicates that the SCE test overpredicts the true aerobic capacity while a negative difference reveals that the SCE test underpredicts. The paired-difference t-test was performed to determine whether the mean differences were significantly different from zero. An alpha level of $p \leq 0.05$ was required for statistical significance. Mean differences were also calculated for the means of SCE-1 and

SCE-2, SCE-3 and SCE-4, baseline SCE with each of the four SCE's, and the treadmill VO_{2max} and the cycle VO_{2max} tests. (NOTE: the units for the mean differences are $ml \cdot kg^{-1} \cdot min^{-1}$)

Pearson Product Moment Correlation Coefficient (r):

A correlation refers to a quantifiable relationship between two variables and the statistic that provides an index of that relationship is called a correlation coefficient (14). When the relationship between two variables can best be described as a straight line, a linear relationship exists, as is the case with these data. Linear relationships can be determined by the product moment correlation (r). The values of r range from +1.00, through 0, to -1.00. The closer the r value is to 1.00, the better the correlation, and therefore, the more accurate the prediction of aerobic capacity. The aerobic capacities from all of the SCE tests were correlated to the aerobic capacity measured during the treadmill VO_{2max} test and the cycle VO_{2max} test. In addition, the following tests were correlated to each other: one, SCE-1 and SCE-2; two, SCE-3 and SCE-4; three, baseline SCE and all four SCE's; and four, the treadmill VO_{2max} test and the cycle VO_{2max} test.

Standard Error of the Estimate (SEE) and %SEE:

The standard error of the estimate (SEE) is a statistical term that provides an indication of the variance or dispersion of individual scores about the computed line of regression (15). SEE is calculated as follows: $SEE = Sy\sqrt{1-r^2}$

where Sy is the standard deviation of the criterion aerobic capacity (treadmill or cycle VO_{2max}) and r^2 is the squared value of the Pearson correlation coefficient, r. The larger the r^2 value and the smaller the Sy, the smaller the SEE value, and therefore, the better the predictive power of the SCE cycle test. (NOTE: the units for the standard errors of the estimate are $ml \cdot kg^{-1} \cdot min^{-1}$.) The %SEE was also calculated in the following manner: %SEE=SEE/mean criterion aerobic capacity. This value simply expresses the standard error relative to mean criterion aerobic capacity.

Total Error (E):

The total error (E) is a statistical term that includes two sources of variation: the SEE and any systematic error that would be indicated by the difference between the regression line and the line of identity (15). Total error is calculated as follows: $E=\sqrt{\sum(y'-y)^2/N}$, where y' is the criterion mean and y is the mean of the SCE test. The smaller the difference between the two means, the smaller the E, and therefore, the better the predictive power of the SCE test.

Analysis of Variance (ANOVA):

Mean aerobic capacities of all five SCE tests (baseline SCE and SCE-1 through SCE-4) were compared using ANOVA with repeated measures. Post-hoc tests were completed when appropriate using single degree-of-freedom contrasts.

Stepwise Multiple Regression Analysis:

Stepwise multiple regression analysis with maximum R^2 (MAXR) improvement was used to develop new prediction equations for males and females. The purpose of this analysis was to determine if new equations could be generated that would improve the estimation $\dot{V}O_{2max}$ from the USAF SCE test. The MAXR technique, developed by Goodnight (16), is considered superior to the stepwise technique alone. According to the SAS User's Guide (16), "the MAXR method tries to find the best one-variable model, two-variable model, and so forth. The MAXR method begins by finding the one-variable model producing the highest R^2. Then another variable, the one that yields the greatest increase in R^2, is added. Once the two-variable model is obtained, each of the variables in the model is compared to each variable not in the model. For each comparison, MAXR determines if removing one variable and replacing it with the other variable increases R^2. After comparing all possible switches, MAXR makes the switch that produces the largest increase in R^2. Thus, the two-variable model achieved is considered the "best" two-variable model the technique can find. Another variable is then added to the model, and the comparing-and-switching process is repeated to find the best three-variable model, and so forth."

Stepwise multiple regression analysis with maximum R^2 (MAXR) improvement was performed, by gender, using the following seven variables measured during the baseline SCE test: age, height, weight, BMI, resting heart rate, final power output, and the mean

of the final two exercise HRs. In the regression model, these seven variables were entered as the independent variables and the aerobic capacity measured from the treadmill VO_{2max} test represented the dependent variable. In an effort to improve prediction accuracy, additional models were run using the following independent variables: one, the same seven variables plus their squared values; two, the seven variables plus their log-transformed values; and three, the seven variables, their squared values, and their log-transformed values. For entry into a regression model, the significance level of the F statistic associated with each independent variable was set at $p \leq 0.05$.

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Results and Discussion

Subject description and adherence

As described in the methods, a total of 207 subjects volunteered to participate in the study and completed the baseline submaximal cycle ergometer (SCE) test. Of these, 134 subjects completed phase I of the project by completing the treadmill test to determine maximum aerobic capacity ($\dot{V}O_{2max}$) and two additional SCE tests (SCE 1 and 2). Additionally, 113 subjects who completed phase I, took the SCE 3 and SCE 4 tests and the cycle ergometer test to determine $\dot{V}O_{2max}$ (phase II). Finally, 102 subjects completed both phases I and II of the project and phase III which included a SCE test developed by the YMCA (YMCA).

During the course of the project a total of 106 subjects did not complete the study. Participants did not finish the eight test protocol for a variety of reasons. Forty-one percent (44/106) of the non completers were dropped by the investigators because their age-fitness classification as described in Appendix K was already filled. In all cases, these subjects were too fit. Fifty-two percent (55/106) dropped out of the testing protocol because of the lack of time or loss of interest. Four (3.7%) of the subjects were not allowed to continue in the project for medical reasons; three had electrocardiographic abnormalities during their treadmill test and one had hypertension. Two subjects dropped out of the study because of an accident that was not related to the project and one resulting from a medical

problem not related to the project.

Table 2 shows the distribution of subjects by gender, age and aerobic capacity for the 134 participants who completed phase I. Most of the age-fitness cells were filled which complies with the statement of work requirements established in Appendix K as modified by Lt. Col. Bisson, M.D. (Table A), except for the low fit subjects. It was difficult to recruit younger unfit subjects who could meet the U.S. Air Force (USAF) height and weight standards. More importantly, the initial $\dot{V}O_{2max}$ cut off for low fit males (< 32 $ml \cdot kg^{-1} min^{-1}$) and females (< 26 $ml \cdot kg^{-1} min^{-1}$) (Appendix K, Table B) was at the 7th percentile of the population norms (1,2). The latter adjusted standards for males (< 35 $ml \cdot kg^{-1} min^{-1}$) and females (< 29 $ml \cdot kg^{-1} min^{-1}$) (Appendix K, Table A) were at the 10th and 15th percentiles of the population norms, respectively. Although a concerted effort was made to recruit low fit subjects the availability of potential participants appeared to be quite small. Perhaps lower fit younger individuals are less likely to volunteer for studies that require physical effort. Also, many of the low fit subjects that were identified were obese and/or could not meet the blood pressure standard. Even though very low fit younger subjects were not available for this study, the matrix found in Table 2 shows a broad distribution of fitness levels based on age and gender.

The physical characteristics and aerobic capacity information found in Table 3 show that the participants used in this study were representative of a normal sample of U.S.

Table 2. Matrix showing the sample size by gender, age and aerobic fitness classification, for subjects completing phase I* of the U.S. Air Force submaximal cycle ergometer study (n=134).

Age, yr	Males			Females		
	L**	M	H	L	M	H
	(<35)	(≥35, <44)	(≥44)	(<29)	(≥29, <37)	(≥37)
1 = 17-24	0	4	6	0	2	5
2 = 25-29	1	2	7	0	2	5
3 = 30-34	2	0	6	4	2	3
4 = 35-39	1	3	3	1	4	5
5 = 40-44	4	3	4	6	3	3
6 = 45-49	4	1	4	1	4	3
7 = 50-54	3	6	3	7	5	2
	n=15	n=19	n=33	n=19	n=22	n=26
	total n = 67 males			total n = 67 females		

* phase I includes subjects who completed a baseline submaximal cycle ergometer (SCE) test, treadmill test to determine maximal aerobic capacity and two additional SCE tests.
** L = low, M = moderate, H = high aerobic capacity by $\dot{V}O_{2max}$ expressed as $ml \cdot kg^{-1} \cdot min^{-1}$.

Table 3. Physical characteristics for subjects who completed phase I* of the U.S. Air Force submaximal cycle ergometer test validation study. Data is for total group (n=134) and by gender (males n=67, females n=67).

	Mean ± SD	Range
Age, yr	38.3 ± 10.5	19.0 - 54.0
Ht**, cm	172.3 ± 9.7	152.4 - 193.4
Wt, kg	72.8 ± 14.3	46.5 - 115.7
BMI	24.4 ± 3.7	15.5 - 38.9
Fat, %	22.1 ± 9.6	4.4 - 44.1
FFM, kg	56.7 ± 12.3	37.3 - 85.1
$\dot{V}O_{2max}$†	40.6 ± 13.7	16.9 - 83.2

	Males (n=67)		Females (n=67)	
	mean ± SD	Range	Mean ± SD	Range
Age, yr	37.7 ± 11.1	19.0 - 54.0	38.9 ± 9.9	19.0 - 54.0
Ht, cm	179.5 ± 6.7	165.5 - 193.4	165.9 ± 6.4	152.4 - 184.8
Wt, kg	81.1 ± 11.3	57.3 - 105.1	66.4 ± 11.9	46.5 - 115.7
BMI	25.2 ± 3.2	19.8 - 36.8	23.6 ± 4.0	15.5 - 38.9
Fat, %	17.0 ± 7.9	4.4 - 32.0	27.9 ± 8.0	14.9 - 44.1
FFM, kg	66.4 ± 7.1	53.4 - 85.1	45.7 ± 5.8	37.3 - 65.3
$\dot{V}O_{2max}$†	48.0 ± 12.8	36.1 - 83.2	33.2 ± 10.1	16.9 - 67.7

* phase I includes subjects who completed a baseline submaximal cycle ergometer (SCE) test, treadmill test to determine maximal aerobic capacity and two additional SCE tests.

** ht = height, wt = weight, BMI = body mass index, fat = percent fat derived from the sum of 7 skinfolds, FFM = fat free mass, $\dot{V}O_{2max}$ = aerobic capacity determined on a treadmill.

† $ml \cdot kg^{-1} min^{-1}$

citizens based on population norms (1,2), except for the $\dot{V}O_{2max}$ of males. The $\dot{V}O_{2max}$ of the males was approximately 5 $ml \cdot kg^{-1} min^{-1}$ higher than found in the population norms. This distribution remained relatively constant for the total group or when the group was dichotomized by gender for subjects who completed phase I (Table 3, n=134), phase II (Table 4, n=113) and phase III (Table 5, n=102). In general, the males averaged: age = 37.7 $\pm$ 11 yr, height = 180 $\pm$ 7 cm, weight = 81 $\pm$ 11 kg, body mass index = 25.2 $\pm$ 3 kg/m^2, fat = 17 $\pm$ 8% and $\dot{V}O_{2max}$ 48.0 $\pm$ 13 $ml \cdot kg^{-1} min^{-1}$ and females: age = 38.9 $\pm$ 10 yr, height = 166 $\pm$ 6 cm, weight = 66 $\pm$ 12 kg, body mass index = 23.6 $\pm$ 4 kg/m^2, fat = 28 $\pm$ 8% and $\dot{V}O_{2max}$ 33.2 $\pm$ 10 $ml \cdot kg^{-1} min^{-1}$ for physical characteristics and aerobic capacity determined on a treadmill.

Cross-validation of USAF submaximal cycle ergometer test

The USAF SCE test was cross-validated with phase I subjects by gender (males n=67, females n=67). Table 6 shows the results from the baseline SCE, SCE 1, and SCE 2 tests compared to the treadmill test to determine $\dot{V}O_{2max}$. These data show that the baseline SCE $\dot{V}O_{2max}$ for the males was modestly lower (2.2 $ml \cdot kg^{-1} min^{-1}$, $p \leq 0.05$) than the treadmill results and the SCE 1 and 2 tests. The SCE 1 and 2 results were similar to the treadmill values. For females the treadmill test $\dot{V}O_{2max}$ was significantly lower than all three SCE tests. In general, the female baseline SCE test was closer to the treadmill $\dot{V}O_{2max}$ than the SCE 1 and 2 values.

Table 4. Physical characteristics for subjects who completed phase II* of the U.S. Air Force submaximal cycle ergometer (SCE) test validation study. Data is for total group (n=113) and by gender (males = 58, females = 55).

Physical Characteristics (n=113)		
	Mean ± SD	Range
Age, yr	38.9 ± 10.3	19.0 - 54.0
Ht** cm	172.7 ± 9.7	152.9 - 193.4
Wt, kg	73.0 ± 14.3	48.3 - 115.7
BMI	24.3 ± 3.7	15.5 - 38.9
Fat, %	22.3 ± 9.9	4.4 - 44.1
FFM, kg	56.9 ± 12.4	37.3 - 85.1
$\dot{V}O_{2max}$†	40.6 ± 13.7	16.9 - 83.2

	Males (n=58)		Females (n=55)	
	Mean ± SD	Range	Mean ± SD	Range
Age, yr	37.9 ± 10.9	19.0 - 54.0	39.9 ± 9.7	19.0 - 54.0
Ht** cm	180.0 ± 11.6	165.5 - 193.4	164.9 ± 5.8	152.9 - 180.0
Wt, kg	80.7 ± 11.6	57.3 - 105.1	64.7 ± 12.1	48.3 - 115.7
BMI	24.9 ± 3.4	19.8 - 36.8	23.7 ± 4.0	15.5 - 38.9
Fat, %	16.7 ± 7.7	4.4 - 31.3	28.9 ± 8.1	14.9 - 44.1
FFM, kg	66.6 ± 7.0	54.5 - 85.1	45.4 ± 5.8	37.3 - 65.3
$\dot{V}O_{2max}$†	48.3 ± 12.7	28.7 - 83.2	32.5 ± 9.5	16.9 - 67.7

* Phase II includes subjects who completed phase I of the project plus two additional SCE tests (SCE 3, SCE 4) and a maximal cycle ergometer test to determine $\dot{V}O_{2max}$.

** ht = height, wt = weight, BMI = body mass index, fat = percent fat derived from the sum of 7 skinfolds, FFM = fat free mass, $\dot{V}O_{2max}$ = aerobic capacity determined on the treadmill.

† $ml \cdot kg^{-1} min^{-1}$

Table 5. Physical characteristics for subjects who completed phase III* of the U.S. Air Force submaximal cycle ergometer (SCE) test validation study. Data is for total group (n=102) and by gender (males = 55, females = 47).

Physical Characteristics (n=102)		
	Mean ± SD	Range
Age, yr	38.4 ± 10.3	19.0 - 54.0
Ht, cm	173.1 ± 9.7	152.9 - 193.4
Wt, kg	73.3 ± 14.1	48.3 - 115.7
BMI	24.3 ± 3.8	15.5 - 38.9
Fat, %	22.1 ± 10.0	4.4 - 44.1
FFM, kg	57.1 ± 12.3	37.3 - 85.1
$\dot{V}O_{2max}$†	41.3 ± 13.7	16.9 - 83.2

	Males (n=55)		Females (n=47)	
	Mean ± SD	Range	Mean ± SD	Range
Age, yr	38.1 ± 10.7	20.0 - 54.0	38.7 ± 9.9	19.0 - 54.0
Ht** cm	180.1 ± 6.0	165.8 - 193.4	164.9 ± 6.0	152.9 - 180.0
Wt, kg	80.4 ± 10.8	63.0 - 105.1	64.9 ± 12.9	48.3 - 115.7
BMI	24.8 ± 3.3	19.8 - 36.8	23.8 ± 4.2	15.5 - 38.9
Fat, %	16.5 ± 7.4	4.4 - 29.0	29.1 ± 8.3	14.9 - 44.1
FFM, kg	66.6 ± 6.6	56.1 - 85.1	45.4 ± 5.9	37.3 - 65.3
$\dot{V}O_{2max}$†	48.3 ± 12.6	28.7 - 83.2	33.0 ± 10.0	16.9 - 67.7

* Phase III includes subjects who completed phase I and II of the project plus the YMCA SCE test.

** ht = height, wt = weight, BMI = body mass index, fat = percent fat derived from the sum of 7 skinfolds, FFM = fat free mass, $\dot{V}O_{2max}$ = aerobic capacity determined on a treadmill.

† $ml \cdot kg^{-1} min^{-1}$

Table 6. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test using phase I subjects.‡

test	Maximum aerobic capacity ($ml \cdot kg^{-1} min^{-1}$)			
	males (n=67)		females (n=67)	
	mean ± SD	range	mean ± SD	range
TMT[1]	48.0 ± 12.8*	26.1 - 83.2	33.2 ± 10.1	16.9 - 67.7
Base[1]	45.8 ± 14.2	22.0 - 87.5	35.5 ± 11.8**†	16.1 - 72.9
SCE 1	48.2 ± 15.1*	22.9 - 97.6	37.1 ± 12.5**	18.1 - 77.3
SCE 2	48.6 ± 16.0*	20.3 - 110.6	38.0 ± 12.7**	17.9 - 81.4

[1] TMT = maximal treadmill test to determine $\dot{V}O_{2max}$,
Base = baseline SCE

* $p \leq 0.05$ from baseline SCE

** $p \leq 0.05$ from TMT

† $p \leq 0.05$ from SCE 2

‡ Phase I included subjects who completed a baseline SCE test, treadmill test to determine $\dot{V}O_{2max}$ and two additional SCE tests.

Table 7. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test using phase I (n=134) subjects.

	Baseline	SCE 1	SCE 2
Males (n=67):			
Mean Difference	-2.2*	0.2	0.6
r	0.85	0.86	0.85
SEE**	6.7	6.5	6.7
% SEE	14.0%	13.5%	14.0%
E**	7.9	7.5	8.4
Females (n=67):			
Mean Difference	2.2*	3.8*	4.8*
r	0.84	0.87	0.86
SEE**	5.5	5.0	5.2
% SEE	16.6%	15.1%	15.7%
E**	6.7	7.2	8.2

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$

** $ml \cdot kg^{-1} min^{-1}$

Table 7 shows that for both males and females the correlations (r) and standard errors of estimate (SEE) for $\dot{V}O_{2max}$ were similar for all SCE tests compared to the actual $\dot{V}O_{2max}$ determined on a treadmill. For males the r_s ranged from 0.85 - 0.86 and the SEEs 6.5 - 6.7 (13.5 - 14.0%) and for females the r_s ranged from 0.84 - 0.87 and SEEs 5.0 - 5.5 (15.1 - 16.6%) compared to the treadmill $\dot{V}O_{2max}$. The total error (E) reflects a small systematic error related to the mean difference of each SCE test when compared to the treadmill test.

These cross-validation statistics show that the USAF SCE test is a valid field test and the first baseline test gives adequate estimates of $\dot{V}O_{2max}$. Further, these results compare favorably, if not better than other reports in the literature using submaximal test ergometry to estimate $\dot{V}O_{2max}$ (see Table 1, review of literature). The second test for males (SCE 1) appeared to improve the estimated mean value for $\dot{V}O_{2max}$, but the r and SEE remained similar to the baseline SCE test values. For the females, the baseline SCE test showed a small overestimation of $\dot{V}O_{2max}$ compared to the actually measured treadmill values. The overestimation $\dot{V}O_{2max}$ became progressively higher with subsequent SCE tests, but the r and SEE values remained similar to the baseline SCE test values. The progressive increase in estimated $\dot{V}O_{2max}$ with subsequent SCE testing reflects a small learning or training effect.

The results from phase II of the study addressed three important issues; one, does the estimate of $\dot{V}O_{2max}$ from the SCE

test relate better to the directly measured $\dot{V}O_{2max}$ determined on a treadmill or on a stationary cycle, and two, does adjusting the power output down or up ($\pm$ 0.5 kp) depending on the HR - power output relationship, improve the estimate of $\dot{V}O_{2max}$ for the SCE test? The third issue relates to the second, in that does having a higher HR within the steady state HR range for estimating $\dot{V}O_{2max}$ from the SCE test provide a more valid test? For example, there are some indications that testing at a higher power output (thus higher steady state HR) provides a higher r and smaller SEE in estimating $\dot{V}O_{2max}$ (1).

Table 8 shows the means $\pm$ SD and ranges, and Table 9 shows the cross-validation statistics for the various SCE tests compared to the treadmill maximum test. The mean differences and cross-validation results for baseline SCE and SCE 1 and 2 for phase II subjects are similar to those shown for the phase I subjects found in Tables 6 and 7, except for the males baseline SCE test mean which was not significantly ($p \geq 0.05$) different than the treadmill $\dot{V}O_{2max}$ value.

The cycle ergometer $\dot{V}O_{2max}$ results were significantly lower compared to the treadmill $\dot{V}O_{2max}$ values ($p \leq 0.05$) for both males (-12%) and females (-13%). These differences are comparable to those found in the literature for subjects of similar age and level of fitness (1). Although the mean values were different between the two maximal tests, the intercorrelation was high for males and moderately high for females (Table 10). Also, the cross-validation statistics for the SCE tests related to the

Table 8. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test using phase II (n=113) subjects.

test	Maximum aerobic capacity ($ml \cdot kg^{-1} min^{-1}$)			
	males (n=58)		females (n=55)	
	mean ± SD	range	mean ± SD	range
TMT	48.3 ± 12.7	28.7 - 83.2	32.5 ± 9.5	16.9 - 67.7
Cycle max	42.3 ± 11.6	23.4 - 69.7	28.3 ± 8.8	12.0 - 54.2
Base[1]	47.0 ± 14.3	22.0 - 87.5	34.2 ± 10.7	16.1 - 72.9
SCE 1	49.3 ± 15.3	22.9 - 97.6	35.7 ± 10.8	18.1 - 75.8
SCE 2	49.9 ± 16.3	20.8 - 110.6	36.7 ± 11.5	17.9 - 81.4
SCE 3	51.2 ± 16.2	23.5 - 104.8	38.1 ± 12.5	15.9 - 78.6
SCE 4	51.0 ± 16.1	20.5 - 107.3	38.2 ± 12.9	18.5 - 81.2

* phase II includes subjects who completed a baseline SCE test and four additional SCE tests, and both treadmill and cycle ergometer tests to determin maximal aerobic capacity.

** TMT = treadmill maximum test, Cycle max = cycle maximum test, Base = baseline SCE test.

Table 9. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test using phase II (n=113) subjects.

	Baseline	SCE 1	SCE 2	SCE 3	SCE 4
<u>Males (n=58):</u>					
Mean Difference	-1.3	1.0	1.6	2.8*	2.6*
r	0.85	0.87	0.86	0.82	0.85
SEE**	6.7	6.3	6.5	7.3	6.7
% SEE	13.9%	13.0%	13.5%	15.1%	13.9%
E**	7.6	7.6	8.4	9.5	8.9
<u>Females (n=55):</u>					
Mean Difference	1.7*	3.2*	4.2*	5.6*	5.7*
r	0.81	0.86	0.83	0.76	0.75
SEE**	5.6	4.8	5.3	6.2	6.3
% SEE	17.2%	14.8%	16.3%	19.1%	19.4%
E**	6.5	6.4	7.6	9.8	10.2

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$

** $ml \cdot kg^{-1} min^{-1}$

Table 10. Cross-validation statistics for the maximum cycle ergometer test (Cycle max) compared to the treadmill maximal test (TMT) using phase II (n=113) subjects.

	Males (n=58)	Females (n=55)
Mean Difference†	-6.1*	-4.2*
r	0.95	0.86
SEE, $ml \cdot kg^{-1} min^{-1}$	4.0	4.8
SEE, %	8.3	14.0
E, $ml \cdot kg^{-1} min^{-1}$	7.3	6.4

† mean difference = TMT $\dot{V}O_{2max}$ - Cycle max $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} min^{-1}$)

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$ (TMT)

cycle ergometer $\dot{V}O_{2max}$ were similar to those found for the treadmill $\dot{V}O_{2max}$ test (data not shown in this report). Thus, the accuracy of estimating $\dot{V}O_{2max}$ from the SCE test was equally as good for the cycle and treadmill $\dot{V}O_{2max}$ tests, except for the absolute mean values. The SCE test estimation of (absolute mean) $\dot{V}O_{2max}$ was more closely related to the treadmill $\dot{V}O_{2max}$ values for both males and females.

The results showed that manipulating the power output $\pm$ 0.5 kp during the SCE tests (SCE 3 and 4, Tables 8 and 9) did not improve the estimation of $\dot{V}O_{2max}$. In general, the cross-validation statistics are similar among all SCE tests except for SCE 3 and 4 for females. The higher mean values for $\dot{V}O_{2max}$ across SCE tests for both males and females could reflect small practice and/or training effects.

To evaluate whether the $\dot{V}O_{2max}$ estimation from the SCE test was improved (>r, <SEE) when subject's trained at a higher power output (i.e., higher steady state HR), the phase II subjects (n=111 two subjects did not change power output among tests) were separated into two groups: (a) those who trained at a lower power output for SCE 1 & 2 and a higher power at SCE 3 & 4 and (b) those who trained at a higher power output for SCE 1 & 2 and a lower power output at SCE 3 & 4. Validation statistics showed that the SCE tests performed at the higher power outputs estimated $\dot{V}O_{2max}$ better for both groups. See Table 11. These results are in general agreement with what has been shown in the literature (1).

Table 11. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test by Power Output† (low to high vs high to low) compared to treadmill $\dot{V}O_{2max}$ (TMT) using phase II (n=111) subjects.

	Groups							
	Low (L) to High (H) Power Output† (n=30)				High to Low Power Output† (n=81)			
	SCE 1 (L)	SCE 2 (L)	SCE 3 (H)	SCE 4 (H)	SCE 1 (H)	SCE 2 (H)	SCE 3 (L)	SCE4 (L)
Mean ± SD, TMT‡	43.3 ±14.7	43.3 ±14.7	43.3 ±14.7	43.3 ±14.7	39.7 ±13.5	39.7 ±13.5	39.7 ±13.5	39.7 ±13.5
Mean ± SD‡, SCE	45.4 ±13.8	46.6 ±13.2	42.7 ±14.9	44.5 ±15.4	41.9 ±15.4	42.5 ±16.4	45.8 ±16.4	44.9 ±16.2
Mean Difference‡	2.1	3.3*	-0.6	1.2	2.1*	2.8*	6.0*	5.1*
Final HR$	132.8	132.5	151.2	147.5	140.6	139.5	123.1	123.9
Final power output	2.6	2.6	3.1	3.1	2.7	2.7	2.2	2.2
r	0.86	0.84	0.91	0.89	0.91	0.89	0.84	0.84
SEE‡	7.5	8.0	6.1	6.7	5.6	6.2	7.3	7.3
% SEE	17.3	18.5	14.1	15.5	14.1	15.6	18.4	18.4
E‡	7.8	8.5	6.3	7.1	6.8	7.9	10.7	10.2

* $p < 0.05$ from TMT.

† low to high power output = lower power output at SCE 1 & 2 vs higher power output at SCE 3 & 4;
high to low power output = higher power output at SCE 1 & 2 vs lower power output at SCE 3 & 4

‡ $ml \cdot kg^{-1} min^{-1}$

$ HR = heart rate, beats/min

USAF submaximal cycle ergometer test compared to the YMCA test

The purpose of phase III of the project was to compare the estimation of $\dot{V}O_{2max}$ determined by the USAF SCE test and the YMCA SCE test. Table 12 shows the mean $\pm$ SD and range for all tests and Table 13 shows the cross-validation statistics for the YMCA SCE test and USAF baseline and SCE 1 tests compared to the treadmill $\dot{V}O_{2max}$ results. The results show that for males the YMCA test is not as accurate as the baseline or SCE 1 tests to estimate $\dot{V}O_{2max}$. In contrast, for females, the YMCA test estimated $\dot{V}O_{2max}$ equally as well if not slightly better than the baseline and SCE 1 tests. Although the estimation of $\dot{V}O_{2max}$ for females was not statistically different ($p \geq 0.05$) among the three SCE tests shown in Table 13, the YMCA test had the highest r, lowest SEE and the mean $\dot{V}O_{2max}$ was closest to the treadmill $\dot{V}O_{2max}$. It is interesting to note that, in particular for females, the estimated $\dot{V}O_{2max}$ from the SCE tests continued to increase over time until the final YMCA test (7th and last cycle test in protocol) where it decreased 5.4 $ml \cdot kg^{-1} min^{-1}$ (Table 12). It is probable that if the YMCA SCE test would have been administered first, its estimated $\dot{V}O_{2max}$ would have been significantly lower than treadmill $\dot{V}O_{2max}$. Even so, our study was not designed to answer that question.

Effects of age and fitness on the USAF SCE test

The sample was dichotomized by age, aerobic fitness category, and whether a subject was a cyclist or non-cyclist in

Table 12. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test using phase III (n=102) subjects.*

test	Maximum aerobic capacity ($ml \cdot kg^{-1} min^{-1}$)			
	males (n=55)		females (n=47)	
	mean ± SD	range	mean ± SD	range
TMT[1]	48.3 ± 12.6	28.7 - 83.2	33.0 ± 10.0	16.9 - 67.7
Cycle[1] max	42.4 ± 11.6	23.4 - 69.7	28.9 ± 9.1	12.0 - 54.2
Base[1]	46.9 ± 14.3	22.0 - 87.5	34.2 ± 11.3	16.1 - 72.9
SCE 1	49.1 ± 15.3	22.9 - 97.6	35.9 ± 11.4	18.1 - 75.8
SCE 2	49.8 ± 16.4	20.8 - 110.6	37.2 ± 12.1	17.9 - 81.4
SCE 3	50.7 ± 16.1	23.5 - 104.8	38.2 ± 13.2	15.9 - 78.1
SCE 4	50.9 ± 16.2	20.5 - 107.3	38.3 ± 13.1	18.5 - 81.2
YMCA[1]	51.9 ± 19.6	27.4 - 135.0	32.8 ± 8.3	18.5 - 64.7

* Phase III includes subjects who completed phase I and II of the project plus the YMCA SCE test.

[1] TMT = maximal treadmill test to determine $\dot{V}O_{2max}$, Cycle max = maximal cycle test to determine $\dot{V}O_{2max}$, Base = baseline SCE test, YMCA = YMCA SCE.

Table 13. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test using phase III (n=102) subjects.

	Baseline	SCE 1	YMCA
<u>Males (n=55):</u>			
Mean Difference	-1.4	0.9	3.6*
r	0.86	0.87	0.63
SEE	6.4	6.2	9.8
% SEE	13.3%	12.8%	20.3%
E	7.4	7.6	15.5
<u>Females (n=47):</u>			
Mean Difference	1.2	2.9*	-0.3
r	0.82	0.86	0.90
SEE	5.7	5.1	4.4
% SEE	17.3%	15.5%	13.3%
E	6.5	6.5	4.3

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$

order to evaluate potential confounding factors that may have affected the accuracy of the SCE test to estimate $\dot{V}O_{2max}$. Table 14 shows the results for phase I subjects who were divided into those 40 yr of age and older and to those 39 yr of age and under. Table 15 shows the cross-validation statistics for the results from Table 14.

As expected, the younger subjects had a significantly higher $\dot{V}O_{2max}$ than the older ones. For males, the values for the mean, r and SEE remained similar among SCE tests and between age groups. The slightly lower r for the older subjects was probably due to the sample becoming more homogeneous when the groups were dichotomized. Correlations can be greatly affected by the range or the spread of the data, thus the SEE becomes an important factor in interpreting the accuracy of a test (3). If anything, the SEEs were lower with the older group. For females, the mean $\dot{V}O_{2max}$ was generally overestimating true $\dot{V}O_{2max}$ and continued to increase across tests, but the values of r and SEE remained constant. In this case, the total error (E) reflected a consistent systematic overestimation of $\dot{V}O_{2max}$. The estimation of $\dot{V}O_{2max}$ from the SCE test is less accurate with the older women (note lower r and higher relative SEE Table 15).

The means, SDs, and ranges of the maximal treadmill and SCE tests for subjects in USAF fitness categories 1, 2, 3 (low-fit) and 4, 5, 6 (high-fit) are shown in Table 16. The cross-validation statistics for the same information are shown in Table 17. The results for the male subjects show that the estimation

of $\dot{V}O_{2max}$ by the SCE test is accurate and well within acceptable standards of validity for the high-fit group, but is less than desirable for the low-fit group. The lower r values and the higher relative SEE values as well as the significant under estimation of $\dot{V}O_{2max}$ compared to the treadmill $\dot{V}O_{2max}$ make the validity of the USAF SCE equation questionable for use in lower-fit males. The 5.8 $ml \cdot kg^{-1} min^{-1}$ underestimation of true $\dot{V}O_{2max}$ of subjects in fitness categories 1, 2, 3 would cause a significant number of miss-classifications of subjects in the negative direction. That is, many male personnel would fail the test when in fact they would be qualified.

In contrast to the males, the results for the female subjects show that the estimation of $\dot{V}O_{2max}$ by the SCE test is reasonably accurate and acceptable for use with the low-fit group. The lower r for the low-fit females is most likely due to the homogeneity of the sample after the total sample was divided. Table 16 shows the greatly reduced range of values for this subgroup. The SEE remained constant compared to the SEE for the total sample of females (see Table 7). The results for the high-fit females remained highly accurate (r and SEE) but showed a large constant systematic overestimation of $\dot{V}O_{2max}$ compared to treadmill $\dot{V}O_{2max}$. Thus, it is the higher-fit females that are causing the systematic error (overestimation of $\dot{V}O_{2max}$) in the total female group (compare Table 16 with Table 7).

The results for the USAF SCE test when groups were dichotomized by whether they trained by cycling or not are shown

Table 14. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test by age category using phase I (n=134) subjects.

	Males (n=67)			
	Younger Adults (n=35) (Age ≤ 39yrs)		Older Adults (n=32) (Age ≥ 40yrs)	
test	mean ± SD $ml \cdot kg^{-1} \cdot min^{-1}$	range	mean ± SD $ml \cdot kg^{-1} \cdot min^{-1}$	range
TMT[1]	53.2 ± 14.0	26.1 - 83.2	42.4 ± 8.6	31.3 - 67.7
Base[1]	51.4 ± 15.8	22.8 - 87.5	39.8 ± 9.0	22.0 - 54.4
SCE 1	54.1 ± 16.9	24.8 - 97.6	41.9 ± 9.3	22.9 - 59.3
SCE 2	54.9 ± 18.1	23.6 - 110.6	41.8 ± 9.7	20.8 - 62.0

	Females (n=67)			
	Younger Adults (n=33) (Age ≤ 39yrs)		Older Adults (n=34) (Age ≥ 40yrs)	
test	mean ± SD $ml \cdot kg^{-1} \cdot min^{-1}$	range	mean ± SD $ml \cdot kg^{-1} \cdot min^{-1}$	range
TMT[1]	38.5 ± 10.6	21.2 - 67.7	28.1 ± 6.3	16.9 - 40.5
Base[1]	40.5 ± 12.9	21.0 - 72.9	30.6 ± 8.2	16.1 - 48.1
SCE 1	42.5 ± 14.3	21.5 - 77.3	31.8 ± 7.6	18.1 - 45.7
SCE 2	43.8 ± 14.4	22.4 - 81.4	32.4 ± 7.5	17.9 - 49.0

[1] TMT = maximal treadmill test to determine $\dot{V}O_{2max}$, Base = baseline SCE test.

Table 15. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test by Age Category using phase I (n=134) subjects.

	Males (n=67)					
	Younger Adults (n=35) (Age ≤ 39yrs)			Older Adults (n=32) (Age ≥ 40yrs)		
	Base[1]	SCE 1	SCE 2	Base	SCE 1	SCE 2
Mean Difference	-1.8	0.9	1.7	-2.7*	-0.6	-0.7
r	0.83	0.86	0.83	0.78	0.77	0.79
SEE, **	7.8	7.1	7.8	5.4	5.5	5.3
% SEE	14.7%	13.3%	14.7%	12.7%	13.0%	12.5%
E, **	9.0	8.7	10.1	6.4	6.0	5.9

	Females (n=67)					
	Younger Adults (n=33) (Age ≤ 39yrs)			Older Adults (n=34) (Age ≥ 40yrs)		
	Base	SCE 1	SCE 2	Base	SCE 1	SCE 2
Mean Difference	2.0	4.0*	5.4*	2.5*	3.7*	4.2*
r	0.88	0.89	0.89	0.62	0.70	0.57
SEE, **	5.0	4.8	4.8	4.9	4.5	5.2
% SEE	13.0%	12.5%	12.5%	17.4%	16.0%	18.5%
E, **	6.4	7.3	8.7	6.9	6.5	7.6

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$

[1] Base = baseline SCE test

** $ml \cdot kg^{-1} min^{-1}$

Table 16. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test by fitness category using phase I (n=134) subjects.

	Males (n=67)			
	Low-fit[1] (n=19) (Fit. Cat. = 1,2,3)		High-fit[1] (n=48) (Fit. Cat. = 4,5,6)	
test	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range
TMT[2]	37.6 ± 7.3	26.1 - 53.2	52.2 ± 12.2	31.3 - 83.2
Base[2]	31.8 ± 4.9	22.0 - 41.1	51.4 ± 12.7	33.2 - 87.5
SCE 1	34.2 ± 4.6	22.9 - 39.6	53.8 ± 14.1	30.8 - 97.6
SCE 2	34.1 ± 5.5	20.8 - 42.6	54.4 ± 15.2	29.8 - 110.6

	Females (n=67)			
	Low-fit (n=30) (Fit. Cat. = 1,2,3)		High-fit (n=37) (Fit. Cat. = 4,5,6)	
test	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range
TMT	27.9 ± 6.2	16.9 - 42.1	37.5 ± 10.6	17.0 - 67.7
Base[1]	26.2 ± 5.2	16.1 - 35.1	43.0 ± 10.2	28.1 - 72.9
SCE 1	28.2 ± 6.0	18.1 - 47.0	44.3 ± 11.7	29.4 - 77.3
SCE 2	29.3 ± 6.6	17.9 - 45.8	45.1 ± 12.1	31.3 - 81.4

[2] TMT = maximal treadmill test to determine $\dot{V}O_{2max}$.
Base = baseline SCE test.

[1] Low-fit = USAF $\dot{V}O_{2max}$ fitness categories 1, 2, and 3.
High-fit = USAF $\dot{V}O_{2max}$ fitness categories 4, 5, and 6.

Table 17. Cross-validation statistics of the U.S. Air Force (USAF) submaximal cycle ergometer (SCE) test by Fitness Category using phase I (n=134) subjects.

	Males (n=67)					
	Low-fit[1] (n=19) (Fit. Cat. = 1,2,3)			High-fit[1] (n=48) (Fit. Cat. = 4,5,6)		
	Base[2]	SCE 1	SCE 2	Base[2]	SCE 1	SCE 2
Mean Difference	-5.8*	-3.4*	-3.5*	-0.8	1.6	2.2
r	0.56	0.66	0.66	0.81	0.83	0.81
SEE,**	6.0	5.5	5.5	7.2	6.8	7.2
% SEE	16.0%	14.6%	14.6%	13.8%	13.0%	13.8%
E,**	8.3	6.3	6.4	7.7	8.0	9.0
	Females (n=67)					
	Low-fit[1] (n=30) (Fit. Cat. = 1,2,3)			High-fit[1] (n=37) (Fit. Cat. = 4,5,6)		
	Base[2]	SCE 1	SCE 2	Base[2]	SCE 1	SCE 2
Mean Difference	-1.8	0.2	1.4	5.5*	6.8*	7.6*
r	0.66	0.68	0.67	0.85	0.88	0.85
SEE,**	4.7	4.5	4.6	5.6	5.0	5.6
% SEE	16.9%	16.1%	16.5%	14.9%	13.3%	14.9%
E,**	5.0	4.8	5.3	7.8	8.7	9.9

* $p \leq 0.05$ from treadmill $\dot{V}O_{2max}$

** $ml \cdot kg^{-1} min^{-1}$

[1] Low-fit = USAF $\dot{V}O_{2max}$ fitness categories 1, 2, and 3.
High-fit = USAF $\dot{V}O_{2max}$ fitness categories 4, 5, and 6.

[2] Base = baseline SCE test

in Tables 18 and 19. The results for males shows a larger SEE for cyclists, particularly on the baseline SCE test. Although, the range of estimated $\dot{V}O_{2max}$ was significantly greater on the higher end, the cross-validation statistics do not reflect any large systematic errors. The mean, r, and SEE generally show similar values as shown in Table 7, except for the SEE for the baseline and SCE 1 tests of cyclists. The underestimate of $\dot{V}O_{2max}$ for the non-cyclists in the baseline SCE test appears to be what affected the total male results (see Table 7). The small sample of cyclists in the female group makes it difficult to make inferences. The cyclists were higher-fit than the non-cyclists (41.9 vs 32.2 $ml \cdot kg^{-1} min^{-1}$, respectively), with the r high, SEE low and no mean differences from the true $\dot{V}O_{2max}$ values. The female non-cyclists showed similar acceptable accuracy of estimation of $\dot{V}O_{2max}$ as shown for the total female group in Table 7, except for the consistent and systematic overestimation of true $\dot{V}O_{2max}$ for all SCE tests.

Thus, when evaluating the influence of age, fitness level, or whether one is training on a cycle has on the USAF SCE test, level of fitness seems to have the most significant effect. In males of USAF fitness categories 1, 2 and 3 the SCE test showed a significant underestimation of $\dot{V}O_{2max}$ and lower overall accuracy (< r and > SEE). For females, the test remained acceptably accurate except for the overestimation of $\dot{V}O_{2max}$ in the higher-fit group (categories 4, 5, and 6).

Table 18. Maximum aerobic capacity (mean ± SD and range) for the U.S. Air Force submaximal cycle ergometer (SCE) test by cyclists vs non-cyclists using phase I (n=134) subjects.

Males (n=67)

	Cyclists (n=19)		Non-cyclists (n=48)	
test	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range
TMT[1]	55.2 ± 15.3	28.7 - 83.2	45.2 ± 10.7	26.1 - 71.0
Base[1]	54.7 ± 16.3	28.4 - 87.5	42.3 ± 11.6	22.0 - 81.7
SCE 1	55.6 ± 17.2	31.1 - 97.6	45.3 ± 13.2	22.9 - 96.2
SCE 2	57.0 ± 16.4	32.7 - 93.8	45.3 ± 14.8	20.8 - 110.6

Females (n=67)

	Cyclists (n=7)		Non-cyclists (n=60)	
test	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range	mean ± SD ($ml \cdot kg^{-1} min^{-1}$)	range
TMT[1]	41.9 ± 13.5	31.0 - 67.7	32.2 ± 9.2	16.9 - 54.8
Base[1]	41.5 ± 16.0	25.3 - 72.9	34.7 ± 11.2	16.1 - 64.2
SCE 1	42.4 ± 17.2	26.2 - 75.8	36.4 ± 11.9	18.1 - 77.3
SCE 2	44.2 ± 19.8	24.6 - 81.4	37.3 ± 11.7	17.9 - 66.8

[1] TMT = maximal treadmill test to determine $\dot{V}O_{2max}$; Base = baseline SCE test.

Table 19. Cross-validation statistics of the U.S. Air Force submaximal cycle ergometer (SCE) test by cyclists vs non-cyclists using phase I (n=134) subjects.

	Males (n=67)					
	Cyclists (n=19)			Non-cyclists (n=48)		
	Base[1]	SCE 1	SCE 2	Base[1]	SCE 1	SCE 2
Mean Difference	-0.5	0.4	1.8	-2.9*	0.1	0.1
r	0.85	0.86	0.90	0.80	0.84	0.80
SEE, **	8.1	7.8	6.7	6.4	5.8	6.4
% SEE	14.7%	14.1%	12.1%	14.2%	12.8%	14.2%
E,**	8.5	8.6	7.2	7.6	7.1	8.8

	Females (n=67)					
	Cyclists (n=7)			Non-cyclists (n=60)		
	Base[1]	SCE 1	SCE 2	Base[1]	SCE 1	SCE 2
Mean Difference	-0.4	0.5	2.2	2.5*	4.2*	5.1*
r	0.96	0.96	0.97	0.82	0.86	0.83
SEE,**	3.8	3.8	3.3	5.3	4.7	5.1
% SEE	9.1%	9.1%	7.9%	16.5%	14.6%	15.[illegible]
E, **	4.5	5.3	7.1	6.9	7.4	8.3

* $p \leq 0.05$ from treadmill VO_{2max}

** $ml \cdot kg^{-1} min^{-1}$

[1] Base = baseline SCE test.

The latter was a systematic error and thus, should be able to be accounted for in a modified equation.

Invalid tests

Table 20 shows the number, reasons for, and distribution of the invalid USAF baseline SCE tests. The data showed that of the 207 baseline SCE tests, 57 (28%) were classified as invalid. Of the 57 invalid tests, 38 (67%) were outright failures, i.e., during the test the subjects stopped cycling because the power output was too intense for them to continue (21%), or more commonly, the test was stopped because the subject's heart rate exceeded the maximum allowable level - 85% of 220-age (79%). The other 19 invalid tests (33%) occurred when the computer logic recommendation to go to the next higher power output was overridden. This was a technician's decision and happened when the heart rate was very close to the maximum allowable level and/or when the fatigue level was too high just before a power output increase was scheduled.

In general, when comparing the group who had invalid tests with the subjects who had valid tests, age, and aerobic capacity were similar, except for the $\dot{V}O_{2max}$ of males (40 vs 48 $ml \cdot kg^{-1} min^{-1}$, respectively). Even though there was a significant difference in $\dot{V}O_{2max}$ of the male subjects who had invalid tests compared to the ones who had valid tests, the mean value for the invalid group was considered average compared to population norms. Also, more females had invalid SCE tests than males (69 vs 31%,

Table 20. Breakdown of invalid tests for baseline U. S. Air Force submaximal cycle ergometer (SCE) tests.

	number (%)
Total Baseline SCE Tests	207
total invalid baseline SCE tests	57 (28% of total)
outright failures	38 (67% of invalid)
computer overrides	19 (33% of invalid)
invalid due to excessive heart rate	45 (79% of invalid)
invalid due to excessive power output	12 (21% of invalid)
invalid tests for males	22 (39% of invalid)
invalid tests for females	35 (61% of invalid)

Average Aerobic Capacity ($\dot{V}O_{2max}$); Subjects with an Invalid Test*	
males:	40 $ml \cdot kg^{-1} min^{-1}$
females:	33 $ml \cdot kg^{-1} min^{-1}$

Fitness categories of subjects who had an invalid baseline SCE (Fitness category is based on the first SCE test):

Fitness Category USAF	no. of males who tested invalid	%total invalid	no. of females who tested invalid	%total invalid
1	2	4	5	9
2	1	2	1	2
3	6	11	6	11
4	5	9	4	7
5	4	7	8	14
6	3	5	6	11

*Aerobic capacity is based on the first successfully completed SCE test to estimate $\dot{V}O_{2max}$.

respectively). Even so, it would be difficult to predict ahead of time who might have an invalid test.

Development of new prediction equations - stepwise multiple regression analysis

As a result of certain problems associated with the current USAF SCE test prediction equations for estimating $\dot{V}O_{2max}$, the following analyses were conducted.

Presented in Tables 21 and 22 are the calculated regression equations, by gender, for predicting VO_{2max} from: one, descriptive variables (age (yr), height (cm), total body weight (kg), and BMI); two, baseline SCE test variables (final power output (kp), resting heart rate (beats/min), and the mean of the final two exercise heart rates ($\bar{X}HR_{final}$); and three, the squared and log forms of both types of variables. The sample used to perform this regression analysis consisted of all subjects who completed both the baseline SCE and the treadmill VO_{2max} tests (n=156: 76 females, 80 males). Two equations emerged for the females (See Table 21). The first equation contained four variables (age, weight, final power output, and $\bar{X}HR_{final}$: r^2=0.76, r=0.87, SEE=4.8 $ml \cdot kg^{-1}min^{-1}$, %SEE=14.8). The SEE value for this new equation is lower than the SEE calculated from the U.S. Air Force equation (baseline SCE test: SEE=5.5 $ml \cdot kg^{-1}min^{-1}$, %SEE=16.6). It is important to note, however, that the application of a regression equation derived from one sample (validation) and applied to another sample from a different study (cross-validation) produces

Table 21. Regression equations for predicting maximal aerobic capacity of adult women from baseline submaximal cycle ergometer test.

VARIABLES*	REGRESSION EQUATIONS	R^2	R	SEE
Females (n=76)				
Age, WT Final WL $\bar{X}$HR final	$\dot{V}O_{2max}$ = 99.039 - 0.502 (Age) - 0.474 (WT) + 8.068 (Final WL) - 0.216 ($\bar{X}$HR final)	0.76	0.87 (14.8%)	4.8
Age, WT (Final WL)^2 ($\bar{X}$HR final)^2	$\dot{V}O_{2max}$ = 92.852 - 0.523 (Age) - 0.451 (WT) + 1.962 (Final WL)^2 - 0.0009 ($\bar{X}$HR final)^2	0.78	0.88 (14.2%)	4.6
Females (n=52)				
Final WL^2 Log (Age) Log (WT)	$\dot{V}O_{2max}$ = 212.435 + 1.966 (Final WL)^2 -15.245 (Log(Age)) - 31.464 (Log(WT))	0.79	0.89 (14.5%)	4.9
Age, (Final WL)^2 ($\bar{X}$HR final)^2 Log (WT)	$\dot{V}O_{2max}$ = 195.762 - 0.517 (Age) + 2.091 (Final WL)^2 - 0.00095 ($\bar{X}$HR final)^2 - 31.452 (Log(Wt))	0.82	0.91 (13.6%)	4.6
Age, (Final WL)^2 ($\bar{X}$HR final)^2 (PF)^2, Log (WT) Log (PF)	$\dot{V}O_{2max}$ = 282.439 - 0.562 (Age) + 2.161 (Final WL)^2 -0.0012 ($\bar{X}$HR final)^2 + 0.016 (PF)^2 - 36.794 (Log(WT)) - 21.833 (Log(PF))	0.84	0.92	4.3 (12.7%)
Age, $\bar{X}$HR final, PF, (Final WL)^2 Log (WT) Log ($\bar{X}$HR final) Log (PF)	$\dot{V}O_{2max}$ = -2325.915 - 0.563 (Age) - 5.195 ($\bar{X}$HR final) + 1.985(PF) + 2.247(Final WL)^2 - 36.923 (Log(WT)) + 681.157 (Log ($\bar{X}$HR final)) - 50.444 (Log (PF))	.86	0.93	4.0 (11.8%)

* WT = total body weight in kg; HT = height in cm; BMI = body mass index; $\bar{X}$HR final = mean of the final two exercising heart rates; PF = percent fat; FFM = fat-free mass in kg; WL = workload or power output.

Table 22. Regression equations for predicting maximal aerobic capacity of adult men from baseline submaximal cycle ergometer test.

VARIABLES*	REGRESSION EQUATIONS	R^2	R	SEE
Males (n=80)				
Age, HT Final WL BMI, $\bar{X}$HR final	$\dot{V}O_{2max}$ = 236.703 - 0.497(Age) - 0.566 (HT) - 1.904 (BMI) + 8.268 (Final WL) - 0.339 ($\bar{X}$HR final)	0.79	0.89	5.7 (12.0%)
Males (n=60)				
Age, WT Log (Final WL)	$\dot{V}O_{2max}$ = 81.723 - 0.498 (Age) - 0.559 (WT) + 26.782 (Log (Final WL))	0.80	0.89	5.8 (12.1%)
Age Final WL PF, $(FFM)^2$	$\dot{V}O_{2max}$ = 70.018 - 0.359 (Age) + 6.917 (Final WL) - 0.860 (PF) - 0.0035 $(FFM)^2$	0.84	0.92	5.2 (10.8%)
Age, BMI (Final WL), PF $(BMI)^2$, $(FFM)^2$ Log (BMI)	$\dot{V}O_{2max}$ = -2736.428 - 0.331 (Age) - 109.113 (BMI) + 7.107 (Final WL) - 1.119 (PF) + 0.960 $(BMI)^2$ - 0.0048 $(FFM)^2$ + 1536.165 (Log(BMI))	0.87	0.93	4.7 (9.8%)

* WT = total body weight in kg; HT = height in cm; BMI = body mass index; $\bar{X}$HR final = mean of the final two exercising heart rates; PF = percent fat; FFM = fat-free mass in kg; WL = workload or power output.

bias estimates (4). That is, during cross-validation the r is always a little lower and SEE larger compared to the calculations derived from the original sample. Therefore these equations may in fact have similar accuracy as the current USAF equations. The second equation also consisted of four variables (age, weight, (final power output)^2, and ($\bar{X}HR_{(final)}$)^2). The inclusion of the squared forms of the variables slightly improved prediction accuracy (r^2=0.78, r=0.88, SEE=4.6 $ml \cdot kg^{-1} min^{-1}$, %SEE=14.2). For the males, only one five-variable equation emerged (variables=age, height, BMI, final power output, and $\bar{X}HR_{(final)}$, r^2=0.79, r=0.89, SEE=5.7 $ml \cdot kg^{-1} min^{-1}$, %SEE=12.0 (See Table 22)).

In an attempt to improve the prediction accuracy, another regression model was calculated which included percent fat (PF) and fat-free mass (FFM) in addition to the above-mentioned variables. Also, the log-transformation values of the variables were added to the above model. Since not all subjects performed body composition analysis, the sample for this model was smaller (n=112: 52 females and 60 males). Several equations for both males and females were generated from this model (See Table 21 for females and Table 22 for males). The "best" (i.e., greater r^2 and r, lower SEE and %SEE) three-variable model for females contained (final power output)^2, the log of age, and the log of weight (r^2=0.79, r=0.89, SEE=4.9, %SEE=14.5). The "best" four-variable model yielded a lower SEE and %SEE (variables=age, (final power output)^2, ($\bar{X}HR_{(final)}$)^2, and the log of weight; r^2=0.82, r=0.91, SEE=4.6, %SEE=13.6).

Six and seven variable models also emerged. As long as a variable adds to the prediction in a significant independent fashion, the more variables contained in a model, the better the predictive accuracy. However, it is important to note that when performing regression analysis on a given sample, the subject to variable ratio must be considered. There must be at least three subjects per variable in the model, and 20 or more subjects per variable is ideal (5). The six-variable model contained the following variables: age, (final power output)^2, ($\bar{X}HR_{final}$)^2, (PF)^2, the log of weight, and the log of PF (r^2=0.84, r=0.92, SEE=4.3, %SEE=12.7). The seven-variable model further decreased the SEE and %SEE (variables=age, $\bar{X}HR_{final}$, PF, (final power output)^2, the log of weight, the log of $\bar{X}HR_{final}$, and the log of PF; r^2=0.86, r=0.93, SEE=4.0, %SEE=11.8).

The "best" three-variable model for the males contained age, weight, and the log of the final power output (r^2=0.80, r=0.89, SEE=5.8, %SEE=12.1). See Table 21. The "best" four-variable model yielded a lower SEE and %SEE (variables=age, final power output, PF, and (FFM)^2; r^2=0.84, r=0.92, SEE=5.2, %SEE=10.8). There were not any six-variable models for the men, however, a seven-variable model did emerge (variables= age, BMI, final power output, PF, (BMI)^2, (FFM)^2, and the log of BMI; r^2=0.87, r=0.93, SEE=4.7, %SEE=9.8).

It is apparent from the new prediction equation models that the inclusion of percent fat and fat free mass (males only) and using the variables squared or a log transformation added

significantly to the estimation of true $\dot{V}O_{2max}$. This has been true in other studies where estimation models have been used. For example, when Jackson and Pollock (4) derived prediction equations for estimating body density (percent fat) they found that the log and quadratic form of the independent variable(s) added significantly to the estimation of percent fat. From a statistical standpoint, variables such as $\dot{V}O_{2max}$, heart rate, power output and body composition can be highly related in a stepwise fashion (low to high intensity), but not at the same constant rate throughout the range of estimation. Therefore, it is entirely probable that the new equations that include PF and FFM, as well as the log or squared variable models will improve the estimation of $\dot{V}O_{2max}$ and in particular, low-fit males and high-fit females. Only further cross-validation will confirm this issue.

Sensitivity and specificity of the SCE Test

The terms sensitivity and specificity, in this case, were used to determine how valid the baseline SCE test was in differentiating between a person who fails the SCE test (Fit. Cat. < 3) versus one who passes (Fit. Cat. ≥ 3). Sensitivity refers to the percentage of low-fit subjects (Fit. Cat. < 3 according to the treadmill $\dot{V}O_{2max}$ test (TMT)) who failed the SCE test. Sensitivity was calculated as follows:

$$\text{Sensitivity} = \frac{TP \times 100}{TP + FN}$$

where TP = true positive (those who failed according to both the SCE test and TMT) and FN = false negative (those who passed by definition of the SCE test but failed according to the TMT). Using phase I (n=134) subjects, the sensitivity of the baseline SCE test was 75% (TP = 15, FN = 5; see Table 23).

Specificity refers to the percentage of subjects who are fit (Fit. Cat. ≥ 3 according to the TMT) who passed according to the SCE test. Specificity was computed as follows:

$$\text{Specificity} = \frac{TN \times 100}{FP + TN}$$

where TN = true negative (those who passed by both the SCE test and TMT) and FP = false positive (those who failed according to the SCE test but passed by definition of the TMT). Specificity of the baseline SCE test was 96% (TN = 109, FP = 5); see Table 23).

As far as the USAF is concerned, the worst situation would be to fail a subject (Fit. cat. < 3) when in fact his or her true $\dot{V}O_{2max}$ is above the acceptable standard. Only 5 of 134 (3.7%) subjects in this study fell into this cell, but if extrapolated over the USAF population, this could be a significant number (see Table 23, false positives). It appears from the results of ourcross-validation study, that the subgroup that would beat the greatest risk of becoming a false positive based on the current SCE test would be the male subjects in fitness category 3 (refer to Table 17)

Table 23. Pass/fail matrix and sensitivity/specificity matrix for phase I (n=134) subjects.

Pass/Fail Matrix

	Base SCE[1] Aerobic capacity	TMT[1] Aerobic capacity
Fit. Cat.[1] < 3 (Fail)	n=20	n=15
Fit. Cat. ≥ 3 (Pass)	n=114	n=119

Sensitivity/Specificity Matrix

		TMT	
		Fit. Cat. < 3	Fit. Cat. ≥ 3
Base SCE	Fit. Cat.[1] < 3	TP = 15	FP = 5
	Fit. Cat. ≥ 3	FN = 5	TN = 109

[1] Base = baseline SCE test, TMT = treadmill maximal test to determine $\dot{V}O_{2max}$ (aerobic capacity), TP = true positive, FN = false negative, FP = false positive, TN = true negative.

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Summary, Conclusions and Recommendations

Summary

Two hundred and seven subjects (males, n=103; females, n=104) between the ages of 18 and 54 years of age volunteered to participate in the U.S. Air Force (USAF) cross-validation study to determine the accuracy of the USAF submaximal cycle ergometer (SCE) test. Of these subjects 134 completed phase I of the project by completing a baseline SCE test, a maximal treadmill test to determine maximum aerobic capacity ($\dot{V}O_{2max}$), and two additional SCE tests (SCE 1 and 2). Additionally, 113 subjects who completed phase I also completed the SCE 3 and 4 tests and a maximal cycle ergometer test to determine $\dot{V}O_{2max}$ (phase II). Finally, 102 subjects completed both phases I and II of the project and completed a submaximal cycle ergometer test developed by the YMCA (phase III).

The USAF SCE test was cross-validated with phase I subjects who were divided by gender (males n=67, females n=67). The analysis showed that the USAF SCE test is a valid test for use with males and females between 19 and 54 yr of age. The cross-validation statistics for males showed that the baseline SCE test underpredicted the actual treadmill $\dot{V}O_{2max}$ by 2.2 $ml \cdot kg^{-1} min^{-1}$, had a moderately high correlation (r=0.85), and acceptably low standard error of estimate (SEE, 6.7 $ml \cdot kg^{-1} min^{-1}$, 14.0%). For the females, the baseline SCE test overestimated the $\dot{V}O_{2max}$ compared to the treadmill test by 2.2 $ml \cdot kg^{-1} min^{-1}$. The correlation of the SCE baseline test for females was moderately

high ($r = 0.84$) with a relatively low SEE (5.5 ml·kg^{-1}min^{-1}, 16.6%). Compared to the baseline SCE, the SCE test 1 and 2 showed no further increase in accuracy for either the males or the females. Repeat testing (SCE 1 vs. SCE 2) showed the test to be highly repeatable (reliable). The mean values for $\dot{V}O_{2max}$ estimates from the SCE 1 and 2 tests were similar to the treadmill maximum values for male subjects, but continued to overestimate the $\dot{V}O_{2max}$ compared to the treadmill values for females.

Further evaluation of the equations based on age, fitness level, and cycling experience showed that level of fitness was an important confounding factor. Fitness level was defined as low-fit which included subjects from USAF fitness categories 1, 2, and 3 (based on the treadmill maximum aerobic capacity test). The high-fit group was selected from USAF fitness categories 4, 5, and 6. For males, a large significant underprediction of estimated $\dot{V}O_{2max}$ from the baseline SCE test was found compared to the treadmill test (-5.8 ml·kg^{-1}min^{-1}) in low-fit males. This underprediction did not occur for the high-fit males or the low-fit females. In contrast, the estimated $\dot{V}O_{2max}$ of the high-fit females significantly overestimated the baseline SCE test values compared to the treadmill $\dot{V}O_{2max}$ (5.5 ml·kg^{-1}min^{-1}). Therefore, the baseline SCE test was considered to correlate well and have an acceptable low SEE compared to the treadmill determined $\dot{V}O_{2max}$. But the data show that the mean $\dot{V}O_{2max}$ values for males were significantly underestimated by the subjects in the USAF low-fit

categories and overestimated by the female subjects in the high-fit categories. Thus, the refinement of these equations would make them very acceptable for use with the total U.S. Air Force population.

Phase II of the project showed that the additional SCE 3 and 4 tests, which manipulated the power output on the SCE test $\pm$ 0.5 kp depending on the subject's maximal, treadmill heart rate, did not improve the reliability of the test. But when subjects were separated as to the SCE tests that estimated $\dot{V}O_{2max}$ from a lower steady heart rate compared to a higher steady state heart rate, differences in validity occurred. That is, subject's $\dot{V}O_{2max}$ estimated from a higher steady state heart rate resulted in a higher r and lower SEE.

The maximal cycle ergometer test to determine $\dot{V}O_{2max}$ showed a 12 and 13% underprediction of the treadmill test to determine $\dot{V}O_{2max}$ for males and females, respectively. It is very clear from the results that the baseline SCE test was closely related to the treadmill $\dot{V}O_{2max}$ test and not the cycle ergometer $\dot{V}O_{2max}$ test.

Phase III of this cross-validation study included a comparison of the YMCA test and the USAF SCE test for estimating $\dot{V}O_{2max}$. For the males, the YMCA test overpredicted the $\dot{V}O_{2max}$ compared to the treadmill test and the r and SEE were not satisfactory ($r = 0.63$, SEE = 9.8 $ml \cdot kg^{-1} min^{-1}$, 20.3%). In contrast, for females, the YMCA test was equally as good (or slightly better) as the baseline SCE test in estimating $\dot{V}O_{2max}$.

An important issue concerning the USAF SCE test is the large

number of invalid tests that occur on initial testing, that is the baseline SCE test. The data show that of the 207 SCE tests administered for this project, 57(28%) were classified as invalid using the USAF software. Most of the invalid tests (79%) were due to the subject's heart rate exceeding that which is acceptable for the computer logic design to accurately calculate $\dot{V}O_{2max}$. That is, heart rate exceeded the value of 85% of the subject's maximum heart rate based on 220 - age. The other factor that caused invalid tests was the computer algorithm which increased the power output excessively so that the subject fatigued and could not complete the protocol. Comparatively, the YMCA protocol only had two invalid tests. Thus, the USAF test in its current form would not be acceptable with such a high failure rate. A later discussion will give suggestions as to how to improve the invalid test rate.

Because of some of the problems associated with the current USAF SCE test prediction equations for estimating $\dot{V}O_{2max}$, a stepwise multiple regression analysis was completed to generate new equations. In general, using the same basic variables as the current USAF SCE test, the predictions were approximately the same for both males and females. The slightly higher correlations and lower SEEs found with the newer equations (Tables 21 and 22) were probably biased because the results were derived from the data of the same population (current study). That is, a cross-validation study with another group of volunteers would probably lower the correlation and increase the

SEE. The equations that were developed at Armstrong laboratory were cross-validated with the results of the study conducted at the University of Florida.

When body composition variables were included in the regression model, such as % body fat and fat free mass, as well as the use of a log or squared variable regression model, the newly developed equations improved in accuracy and appear to be superior to the current equations used in the USAF SCE test. This cannot be fully answered until cross-validation studies of the newer equations are conducted.

The final aspect of the study looked at sensitivity and specificity of the baseline SCE test. The test showed a sensitivity of 75% and a specificity of 96%. Thus, some subjects were definitely mis-classified. The most important problem with mis-classification would be a false positive test, that is those subjects who would fail the USAF minimum standard for aerobic capacity (fitness category 1 or 2) based on the results of the SCE test, but would actually pass the test according to the measured treadmill $\dot{V}O_{2max}$. Five of 134 persons tested (3.7%) were classified as false positives in this study. Although this number is small, extrapolating over the USAF population would make the problem significant. It is clear from the results of the cross-validation study, that the subjects who would have the largest risk of becoming a false positive based on the current SCE test, would be male subjects in fitness category 3.

Conclusions and Recommendations

Based on the findings of this study the following conclusions and recommendations are made.

1) the USAF SCE test is a valid test for use with males and females between the ages of 19 and 54 yr. In the overall results from the baseline SCE test, the 2.2 $ml \cdot kg^{-1} min^{-1}$ underprediction of $\dot{V}O_{2max}$ for the males and the 2.2 $ml \cdot kg^{-1} min^{-1}$ overprediction of $\dot{V}O_{2max}$ for females would be acceptable. The problem lies in that most of this under and overprediction occurs in the lower-fit (USAF fitness categories 1, 2, 3) males, and the overprediction in the higher-fit (USAF fitness categories 4, 5, 6) females. The accuracy of the estimation of $\dot{V}O_{2max}$ is lowered for the males who are subdivided into the low-fit category. As stated in the results section, the underpredicition and overprediction of $\dot{V}O_{2max}$ will cause many subjects to be mis-classified as to their actual level of fitness. This becomes a particular problem for the category 3 males, who in fact, could pass the USAF fitness standard (USAF category 3 and above) from the maximal treadmill test and because of the 5.5 $ml \cdot kg^{-1} min^{-1}$ underprediction of $\dot{V}O_{2max}$ from the SCE test, may fail the test (false positive). The overprediction of someone in a higher classification is less problematic.

It is recommended that the USAF modify their current equation or develop a new one that would more accurately estimate $\dot{V}O_{2max}$ for males in fitness categories 1, 2, and 3. Secondly, the current equation should be modified to accommodate the

overprediction of $\dot{V}O_{2max}$ for females. It is recommended that the USAF evaluate the newly developed SCE prediction equations (see Tables 21-22) to estimate $\dot{V}O_{2max}$. From this preliminary analysis it appears that the addition of % fat and fat free mass as variables, including a log or squared variable model, may enhance the accuracy of estimating $\dot{V}O_{2max}$. Importantly, the use of squared variable or log terms in the regression analysis model, suggests that the variables used to estimate $\dot{V}O_{2max}$ are not a linear function. Thus, the addition of these new factors (FFM, % body fat) may minimize the underprediction with lower-fit males and overprediction of females. Adequate fine tuning of these new SCE test equations would require some additional cross-validation studies with specific subgroups of subjects.

2) It is concluded that the USAF SCE test results reflect the $\dot{V}O_{2max}$ determined from a maximal treadmill test (mean value) and not from a maximal cycle ergometer test.

3) It is concluded that the manipulation of the power output + 0.5 kp (from the algorithm derived power output) when the subjects steady state heart rate during the test is at the low end of the acceptable range, does improve the estimation of $\dot{V}O_{2max}$. Thus, appropriate adjustments in the power output (+0.5 kp) are recommended to improve the accuracy of the test for subjects who are required an additional trial.

4) The YMCA SCE test did not estimate $\dot{V}O_{2max}$ as well as the USAF SCE test for males, but showed as favorable a result as compared to the USAF SCE test for females. These findings would

not justify incorporating the YMCA test as the new USAF SCE test.

5) The current algorithm for the USAF SCE test resulted in too many invalid baseline tests. Thus, in its current form, the SCE test would not be recommended for wide use in the USAF population. The high failure rate would not be cost effective, and would be discouraging for personnel taking the test and the test administrators. Based on the comments concerning the invalid tests, the following recommendations should be considered. A three minute initial warm-up stage, such as the one used by the YMCA test, should be evaluated. The subject's heart rate response to the first three minute stage is dependant upon his or her level of fitness. The less fit the subject, the greater his/her heart rate response would be, thus prompting the selection of a series of lower power outputs. The initial 3 minute adjustment period of the USAF SCE test is intended to serve this purpose. The problem with the USAF SCE test protocol is that the first power output progression decision is made after only 45 seconds of exercise and the second after 1:50 minutes of exercise. This is not enough time for a sufficient fitness level based heart rate response to occur. For example, an unfit subject may fatigue rapidly after 2 minutes of exercise, experiencing a much greater heart rate increase at a given power output than was predicted from the heart rate response over the first 1:50 minutes of exercise. Thus, the algorithm "needs more time" to make the proper adjustments so that the subject's heart rate and power output is set at the appropriate level.

Another factor in the USAF test algorithm that should be evaluated is the heart rate difference allowed ($\pm$ 3 beats/min) between the last heart rate's obtained during the 10 seconds of the two minutes of the final exercise stage. The YMCA test allows for a heart rate difference of $\pm$ 5 beats/min during the last 10 seconds of the final two minutes of the stage. Thus, the YMCA SCE test has a 40% larger heart rate window to accept the test as valid. Increasing the heart rate range should not affect the accuracy of the test and may avoid some invalid tests. In our series, six invalid tests would have been accepted. Additionally, the YMCA test protocol allows a test to continue indefinitely at a given power output. This allows time for the subject to reach a steady state and reduces the chances of having to repeat a test.

Knowing the subject's level of fitness prior to testing is an important aspect of the current USAF SCE test algorithm. The initial power output is selected based on age, gender, weight and activity level of the subject. The Unit Fitness Monitor Instructor Manual for Cycle Ergometry states that, to be considered active, an individual should play sports vigorously at least 20 minutes, 3 times per week. On the other hand, the USAF SCE software considers a subject active if he or she exercises vigorously at least 2 times per week. The former exercise standards are supported by both the American College of Sports Medicine and the American Heart Association. Both groups recommend a minimum of 3 days a week, 20 - 30 minutes of moderate

to vigorous exercise to attain optimal aerobic training benefits. Therefore, it is suggested that the USAF algorithm be modified to reflect these criteria.

Finally, the reliability of the heart rate monitors should be considered. Any malfunctions or other types of problems with heart rate transmitter placement, etc. will cause tester and subject inconvenience and invalid tests. The Polar CIC models that were used in this project were, for the most part, accurate. We compared its accuracy with a direct lead hook-up to an exercise electrocardiogram machine. The Polar unit did remarkably well when installed correctly. However, there are some potential problems. A) On female subjects, the bottom of the brassiere generally lies exactly where the polar chest strap should be placed. This often presented an installation problem which resulted in poor signal conduction. B) The polar elastic straps also lost elasticity quickly. Sometimes physical changes could be seen in the strap in under 10 uses. C) Additionally, the chest strap transmitter, with the watch receiver, seems to have a range of only about 1 meter and is subject to transmission interference by objects such as the cycle ergometer handle bars. This often required moving the receiver to different locations on the Monark cycle ergometer, while the test was actually being conducted. These problems seem to be worse with the Polar Favor model. The problems associated with any heart rate monitor would be problematic to technicians in the USAF who are conducting the test. Obviously the more error free the system, the greater the

success.

6) It is recommended that once the USAF SCE test cross-validation study report is evaluated, a summit conference be held among the appropriate individuals. The purpose of this meeting would be to further evaluate the final report of this project and to determine what is the next step.

The investigators feel that the USAF SCE test is a valid tool for estimating aerobic capacity of Air Force personnel. With some modifications, the test could be more applicable for both males and females and personnel of varied levels of fitness. Other technical considerations, such as avoiding invalid tests, and training the technicians to administer the test properly, will enhance its accuracy and cost effectiveness.

Appendix A:
24-Hour Health History and Activity Questionnaire.

University of Florida
Center for Exercise Science
Rm 27, Florida Gym
Gainesville, FL 32611
(904) 392-9575

USAF Study [illegible]093:
Cross Validation of Submaximal Cycle Ergometry
Estimates of Aerobic Capacity
Pre-Evaluation Questionnaire

Name: ______________________ **Date:**__________ **Time:**__________

		NO	YES
1.	Are you pregnant?	____	____
2.	Do you have any physical limitations that would prevent you from riding a stationary bike properly?	____	____
3.	Have you been hospitalized within the past 5 days?	____	____
4.	Have you donated blood or have you lost an equivalent amount of blood from injury within the past 15 days?	____	____
5.	Have you had alcohol, tobacco, caffeine, or decongestants in the past 12 hours?	____	____
6.	Have you performed any strenuous activity in the past 12 hrs?		
7.	Have you eaten in the past 3 hours?	____	____

- How long has it been since you last meal or snack? __________hrs.
- List the meal/snack last eaten.__________

____

8.	Have you felt chilled or sweaty for more than 5 of the past 20 minutes?	____	____
9.	Have you recently been ill or injured?	____	____
10.	Did you get enough sleep in the past 24 hours?	____	____

- How much sleep did you get last night? ____hrs.
- How much sleep do you normally get?________hrs.

11. If you take any medications, please list below.

____

____

12. What medications, including aspirin, have you taken today?______________________________

13. Describe your general feelings by checking one of the following.

_____ Excellent _____ Good _____ Very good
_____ Bad _____ Very bad
_____ Neither bad nor good
_____ Terrible

Please sign and date below.

______________________________ ______________
Signature Date

Appendix B: USAF Maximum Allowable Weight VS. Height Chart for Males and Females

Weight Charts - Women (see note)

HEIGHT (IN INCHES)	MAXIMUM ALLOWABLE WEIGHT (MAW)	INTERPOLATED WEIGHT "1/4"	INTERPOLATED WEIGHT "1/2"	INTERPOLATED WEIGHT "3/4"
60	136	136 1/2	137	137 1/2
61	138	138 3/4	139 1/2	140 1/4
62	141	141 1/4	141 1/2	141 3/4
63	142	143	144	145
64	146	147	148	149
65	150	151 1/4	152 1/2	153 3/4
66	155	156	157	158
67	159	160 1/4	161 1/2	162 3/4
68	164	165	166	167
69	168	169 1/4	170 1/2	171 3/4
70	173	174	175	176
71	177	178 1/4	179 1/2	180 3/4
72	182	183 1/2	185	186 1/2
73	188	189 1/2	191	192 1/2
74	194	195 1/4	196 1/2	197 3/4
75	199	200 1/2	202	203 1/2
76	205	206 1/4	207 1/2	208 3/4
77	210	211 1/4	212 1/2	213 3/4
78	215	216 1/2	218	219 1/2
79	221	222 1/4	223 1/2	224 3/4
80	226	227 1/2	229	230 1/2

WEIGHT CHARTS - MEN (see note)

HEIGHT (IN INCHES)	MAXIMUM ALLOWABLE WEIGHT (MAW)	INTERPOLATED WEIGHT "1/4"	INTERPOLATED WEIGHT "1/2"	INTERPOLATED WEIGHT "3/4"
60	153	153 1/2	154	154 1/2
61	155	155 3/4	156 1/2	157 1/4
62	158	158 1/2	159	159 1/2
63	160	161	162	163
64	164	165 1/4	166 1/2	167 3/4
65	169	170 1/4	171 1/2	172 3/4
66	174	174 1/4	175 1/2	176 3/4
67	179	180 1/4	181 1/2	182 3/4
68	184	185 1/4	186 1/2	187 3/4
69	189	190 1/4	191 1/2	192 3/4
70	194	195 1/4	196 1/2	197 3/4
71	199	200 1/2	202	203 1/2
72	205	206 1/2	208	209 1/2
73	211	212 3/4	214 1/4	216
74	218	219 1/2	221	222 1/2
75	224	225 1/2	227	228 1/2
76	230	231 1/2	233	234 1/2
77	236	237 1/2	239	240 1/2
78	242	243 1/2	245	246 1/2
79	248	249 1/2	251	252 1/2
80	254	255 1/4	257 1/2	258 3/4

NOTE: For every inch under 60 inches, subtract 2 pounds from the MAW. For

Appendix C:
Informed Consent to Participate in Research

Informed Consent to Participate in Research

J. Hillis Miller Health Center
University of Florida
Gainesville, Florida 32610

You are being asked to participate in a research study. This form is designed to provide you with information about this study and to answer any of your questions.

1. **TITLE OF RESEARCH STUDY**

   Cross Validation of Submaximal Cycle Ergometry Estimates of Aerobic Capacity.

2. **PRICIPAL INVESTIGATOR(S)**

   Michael L. Pollock, Ph.D.

   Co-Investigators: James Graves, Ph.D.
   David Lowenthal, M.D.
   Linda Garzarella, M.S.
   Diego de Hoyos, M.S.
   Galila Werber, M.S.
   Matt Beekley, B.S.

3. **THE PURPOSE OF THE RESEARCH**

   The purpose of this study is to cross validate the Astrand-Rhyming submaximal cycle ergometry (SCE) test as modified by the United States Air Force (USAF). The SCE is a test of a persons fitness level and is conducted on a stationary bicycle. This experiment will assist in creating USAF fitness testing standards for men and women ages 17 to 54.

4. PROCEDURES FOR THIS RESEARCH

This study will last about three weeks. The testing will involve a minimum of seven visits (about 1 hour per visit). All testing will be done at the Center for Exercise Science. **Visit 1** will be an orientation. You will receive a full explanation of the study, including its benefits and risks. You will also be asked to complete an informed consent form, a medical history form and an exercise activity questionnaire. A submaximal bicycle test (SCE) will also be conducted. This test, on the stationary bicycle, involves pedaling against increasing workloads for a period of about ten minutes. You will be asked to wear a heart rate monitor which consists of a wristwatch and an elastic strap worn just below the chest.

On **Visit 2**, a maximal treadmill exercise test will be performed. This test involves walking/jogging on a treadmill until you are maximally fatigued. This test will last about 10 minutes. During this test, your heart, blood pressure, and breathing will be monitored. You will wear headgear with an attached mouthpiece to monitor your breathing. You will also wear electrodes to monitor how your heart responds to exercise. (Continued on page 4.)

5. POTENTIAL RISKS OR DISCOMFORTS

If you wish to discuss these or any other discomforts you may experience, you may call the Project Director listed in #2 of this form.

Endurance exercise testing is associated with a small risk of cardiovascular complications. The risk for exercise testing is about three to four non-fatal incidents (events) in 10,000 graded exercise tests (GXTs), and one fatal event per 25,000 tests in a hospital population. The risks will be minimized in this study as all personnel involved in testing are experienced in exercise testing. Additionally, you will be screened prior to testing. If this screening reveals cardiovascular disease, you will be excluded from the study. Finally, a physician will be present for all male subjects over the age of 40 and all female subjects over the age of 50. Subjects may expect fatigue and breathlessness accompanying the exercise testing. Following the testing, subjects may experience muscle soreness. This is temporary and normal and will not interfere with normal daily activities.

4. PROCEDURES FOR THIS RESEARCH (continued from p. 2)

During **Visits 3-6** you will repeat the SCE test like in visit 1. During one of these visits, your body fat percentage and lung function will also be estimated. Body fat percentage is estimated by measuring the thickness of skinfolds at several sites on the body. Lung function is measured by breathing into a spirometer while wearing noseclips.

On **Visit 7** (final visit), you will perform another test to maximal exhaustion (like in visit 2), except this test will be done on a stationary bike instead of the treadmill. During this test, your heart, blood pressure, and breathing will be monitored. You will wear headgear with an attached mouthpiece to monitor your breathing. You will also wear electrodes to monitor how your heart responds to exercise.

6. POTENTIAL BENEFITS TO YOU OR TO OTHERS

Determining whether the SCE is a reliable estimate of aerobic capacity has several benefits. Using the SCE test requires less equipment and personnel. Older populations and higher risk populations can also be tested more safely. Benefits to the subjects in this experiment include an evaluation of cardiorespiratory (heart/lung) fitness and body composition (level of fatness).

7. ALTERNATIVE TREATMENTS OR PROCEDURES, IF APPLICABLE

Subjects have the alternative of not participating in this study.

8. GENERAL CONDITIONS

I understand that will ______/ will not __X___ receive money for my participation in this study. If I am compensated, I will receive: ____

____

I understand that I will _____/ will not __X___ be charged additional expenses for my participation in this study. If I am charged additional expenses these will consist of: ____________________________

____

I understand that I am free to withdraw my/ my child's consent and discontinue participation in this research project at any time without this decision affecting my/ my child's medical care. If you have any question regarding your rights as a subject, you may phone (904) 392-3063.

In the event of my/ my child's sustaining a physical injury which is proximately caused by this experiment, __professional______ care received at the J. Hillis Miller Health Center exclusive of hospital expenses will be provided to me without charge. This exclusion of hospital expenses does not apply to patients at the Veterans Administration Medical Center (VAMC) who sustain physical injury during participation in VAMC-approved studies. It is understood that no form of compensation exists other than those described above.

I also understand that the University of Florida and the Veterans Administration Medical Center will protect the confidentiality of my records to the extent provided by Law. The Study Sponsor, Food and Drug Administration or either Institutional Review Board may ask to review my records, however the records will remain confidential as only a number and initial will be used.

9. SIGNATURES

I have fully explained to ____
the nature and purpose of the above-described procedure and the benefits and risks that are involved in its performance. I have answered and will answer all questions to the best of my ability. I may be contacted at telephone number____________________

______________________________ ____________
Signature of Principal or Co-Principal Investigator Obtaining Consent — Date

I have been fully informed of the above-described procedure with its possible benefits and risks and I have received a copy of this description. I have given permission of my/ my child's participation in this study.

______________________________ ____________
Signature of Patient or Subject or Relative or Parent or Guardian (specify) — Date

______________________________ ____________
Signature of Child (7 to 17yrs. of age) — Date

______________________________ ____________
Signature of Witness — Date

Appendix D:
Demographic Information and Medical History

CENTER FOR EXERCISE SCIENCE
UNIVERSITY OF FLORIDA, RM 27 FLG
GAINESVILLE, FL 32611
904-392-9575

DEMOGRAPHIC INFORMATION

NAME______________________________ DATE_____/_____/_____
Last First MI Month Day Year

AGE__________ DATE OF BIRTH _____/_____/_____
Month Day Year

SOCIAL SECURITY #_____-____-_____ PHONE #______________

HEIGHT ______ in___ cm___

WEIGHT ______ lb___ kg___

RESIDENCE____
Street

____
City State Zip Country

REFERRING PHYSICIAN________________________________

SURGEON (if applicable)____________________________

HOME PHYSICIAN (if different from Referring M.D.)____________

ADDRESS____
Street

____
City State Zip Country

Sex ___ Male
___ Female

Race ___ White
___ Black
___ Asian
___ Hispanic
___ Other: ________________

Marital Status

___ Single
___ Married # years:__________
___ Divorced or separated # years:__________
___ Widowed # years:__________

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GAINESVILLE, FL 32611
904-392-9575

NAME______________________________ ID#______________________
DATE______________________

CARDIOVASCULAR HISTORY

Answer the following questions, indicating the month and year of the event of diagnosis where appropriate.

	Yes	No	Month/Year
1. Has a doctor ever told you that you have heart disease?	___	___	_____/_____
2. Have your ever had a heart attack?	___	___	_____/_____

If more than one heart attack, list date(s):

_____/_____
mo yr

_____/_____
mo yr

_____/_____
mo yr

3. Have you had coronary artery bypass graft surgery? ___ ___

If yes, list date(s) and number of grafts:

_____/_____ # grafts: ___1 ___2 ___3 ___4+
mo yr
_____/_____ # grafts: ___1 ___2 ___3 ___4+
mo yr
_____/_____ # grafts: ___1 ___2 ___3 ___4+
mo yr

4. Have you ever had a stroke? ___ ___ _____/_____

If more than one stroke,

_____/_____
mo yr
_____/_____
mo yr
_____/_____
mo yr

		Yes	No	Month/Year
5.	Do you have hypertension (high blood pressure)?	___	___	_____/____

If yes, how long have you had hypertension?

_____ less than 1 year
_____ 1-5 years
_____ 6-10 years
_____ more than 10 years

		Yes	No	Month/Year
6.	Do you have diabetes mellitus?	___	___	_____/____
7.	Do you take insulin for diabetes?	___	___	

If yes, how long have you taken insulin?

___ less than 1 year
___ 1-5 years
___ 6-10 years
___ more than 10 years

		Yes	No	Month/Year
8.	Do you take oral hypoglycemics for diabetes?	___	___	
9.	Do you have a cardiac pacemaker?	___	___	

If yes, how long have you had a cardiac pacemaker?

___ less than 1 year
___ 1-5 years
___ 6-10 years
___ more than 10 years

		Yes	No	Month/Year
10.	Have you had a carotid endarterectomy?	___	___	
11.	Has your doctor ever told you that you have a heart valve problem?	___	___	_____/____
12.	Have you had heart valves replacement surgery?	___	___	_____/____

If yes, what heart valves were replaced?
___ mitral ___ aortic

		Yes	No	Month/Year
13.	Have you had cardiomyopathy?	___	___	_____/____
14.	Have you had a heart aneurysm?	___	___	_____/____

	Yes	No	Month/Year
15. Have you had heart failure?	___	___	_____/____
16. Have you ever suffered cardiac arrest?	___	___	_____/____

17. OTHER MEDICAL PROBLEMS: Indicate if you have had any of the following medical problems:

Past	Now	
____	____	Alcoholism
____	____	Allergies
____	____	Anemia
____	____	Arthritis
____	____	Asthma
____	____	Back injury or problem
____	____	Blood clots
____	____	Bronchitis
____	____	Cirrhosis
____	____	Claudication
____	____	Elbow or shoulder problems
____	____	Emotional disorder
____	____	Eye problems
____	____	Gall bladder disease
____	____	Glaucoma
____	____	Gout
____	____	Headaches
____	____	Hemorrhoids
____	____	Hernia
____	____	Hip, knee or ankle problems
____	____	Intestinal disorders
____	____	Kidney disease
____	____	Liver disease
____	____	Lung disease
____	____	Mental illness
____	____	Neurologic disorder
____	____	OB/GYN problems
____	____	Obesity/overweight
____	____	Phlebitis
____	____	Prostate trouble
____	____	Rheumatic fever
____	____	Seizure disorder
____	____	Stomach disease
____	____	Thyroid disease
____	____	Tumors or cancer - List type:____________________
____	____	Ulcers
____	____	Other - specify:____________________

18. SURGICAL PROCEDURES: Indicate if you have had any of the following surgeries, and if so, the appropriate date.

Yes No Month/Year

____ ____ ______/____Adhesion repair
____ ____ ______/____Appendectomy
____ ____ ______/____Back surgery
____ ____ ______/____Bladder surgery
____ ____ ______/____Bowel surgery
____ ____ ______/____Breast surgery
____ ____ ______/____Cataract surgery
____ ____ ______/____Gall bladder surgery
____ ____ ______/____Hemorrhoid surgery
____ ____ ______/____Joint surgery
____ ____ ______/____Kidney surgery
____ ____ ______/____Lung surgery
____ ____ ______/____OB/GYN surgery
____ ____ ______/____Prostate surgery
____ ____ ______/____Stomach surgery
Other - specify:____________________________________
____

19. MEDICATIONS: Indicate the medicines you currently use on a regular basis.

Yes No
___ ___Allergy medicines/antihistamines
___ ___Antacids
___ ___Antibiotics
___ ___Anti-arrhythmics
___ ___Anti-inflammatory agents
___ ___Aspirin
___ ___Asthma medicines
___ ___Beta blockers
___ ___Birth control pills
(# of years: __0-1 __1-5 __5-10 __10+)
___ ___Blood pressure medicines
___ ___Blood thinners
___ ___Cortisone
___ ___Diabetes medicines/insulin
___ ___Diuretics/"water pills"
___ ___Gout medicines
___ ___Heart medicines
___ ___Hormones/estrogen
___ ___Laxatives
___ ___Nitroglycerin
___ ___Pain medicines
___ ___Psychiatric medicines/anti-depressants
___ ___Sedatives/sleeping pills
___ ___Seizure medicines

	Yes	No
Thyroid medicines	___	___
Tranquilizers	___	___
Vitamins/iron	___	___
Other - specify:______________________________		
____		

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904-392-9575

NAME____________________________ ID#____________________
DATE____________________

FAMILY HEALTH HISTORY

A. If any members of your immediate family have or have had any of the following conditions, indicate their age at the time of the event:

	Father	Mother	Brother(s)	Sister(s)
Heart Attack	___yr	___yr	___yr	___yr
Stroke	___yr	___yr	___yr	___yr
Coronary Artery Disease	___yr	___yr	___yr	___yr
If deceased, note age at time of death	___yr	___yr	___yr	___yr

B. Indicate if any members of your immediate family have or have had the following conditions by marking the appropriate lines.

	Father	Mother	Brother(s)	Sister(s)
High Blood Pressure	___yr	___yr	___yr	___yr
High Cholesterol	___yr	___yr	___yr	___yr
Diabetes	___yr	___yr	___yr	___yr
Obesity	___yr	___yr	___yr	___yr

Appendix E:
Physical Activity Questionnaire

CENTER FOR EXERCISE SCIENCE
UNIVERSITY OF FLORIDA, RM 27 FLG
GAINESVILLE, FL 32611
904-392-9575

NAME________________
ID#________________
DATE________________

ACTIVITY STATUS

1. Please indicate your usual activities.

		Frequency per month					Minutes per session			
		1-4	5-8	9-12	13-16	17+	0-20	20-40	40-60	60+
___	Badminton	___	___	___	___	___	___	___	___	___
___	Baseball/softball	___	___	___	___	___	___	___	___	___
___	Boating	___	___	___	___	___	___	___	___	___
___	Bowling	___	___	___	___	___	___	___	___	___
___	Cycling (motor)	___	___	___	___	___	___	___	___	___
___	Cycling (road)	___	___	___	___	___	___	___	___	___
___	Cycling (stationary)	___	___	___	___	___	___	___	___	___
___	Dancing (aerobic)	___	___	___	___	___	___	___	___	___
___	Dancing (social)	___	___	___	___	___	___	___	___	___
___	Golf (ride)	___	___	___	___	___	___	___	___	___
___	Golf (walk)	___	___	___	___	___	___	___	___	___
___	Gymnastics	___	___	___	___	___	___	___	___	___
___	Hiking	___	___	___	___	___	___	___	___	___
___	Horseback riding	___	___	___	___	___	___	___	___	___
___	Hunting, fishing	___	___	___	___	___	___	___	___	___
___	Jogging/running	___	___	___	___	___	___	___	___	___
___	Martial arts	___	___	___	___	___	___	___	___	___
___	Racquet/handball	___	___	___	___	___	___	___	___	___
___	Rope jumping	___	___	___	___	___	___	___	___	___
___	Rowing, canoeing	___	___	___	___	___	___	___	___	___
___	Sailing	___	___	___	___	___	___	___	___	___
___	Skating	___	___	___	___	___	___	___	___	___
___	Skiing (cross ctry)	___	___	___	___	___	___	___	___	___
___	Skiing (downhill)	___	___	___	___	___	___	___	___	___
___	Skiing (water)	___	___	___	___	___	___	___	___	___
___	Soccer/football	___	___	___	___	___	___	___	___	___
___	Swimming	___	___	___	___	___	___	___	___	___
___	Table tennis	___	___	___	___	___	___	___	___	___
___	Tennis	___	___	___	___	___	___	___	___	___
___	Volleyball	___	___	___	___	___	___	___	___	___
___	Walking	___	___	___	___	___	___	___	___	___
___	Weight training	___	___	___	___	___	___	___	___	___
___	Yardwork, gardening	___	___	___	___	___	___	___	___	___
___	Other - specify:									

2. Does your usual job require sustained physical activity?

___ Yes ___ No ___ Not employed ___ Not applicable (retired)

3. How would you rate your physical fitness (endurance)?

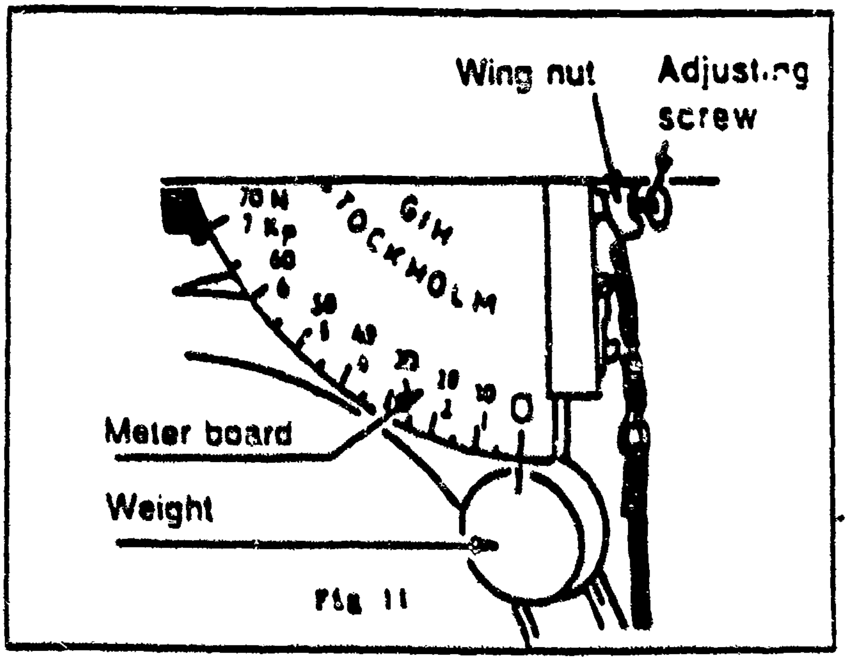
low			medium			high
1	2	3	4	5	6	7

4. How would you rate your strength?

low			medium			high
1	2	3	4	5	6	7

Appendix F: Description of Monark Cycle Ergometer Calibration

Monark Cycle Ergometer calibration is achieved by first turning the resistance belt to zero on the free standing ergometer. Next, the workload meter board is pulled against the adjusting screw (Figure 1). Next, the adjusting screw is loosened by loosening the wing nut and is moved so that the mark on the pendulum weight is even with the 0 Kp mark. Finally, the adjusting screw is secured by tightening the wing nut.



(From: Unit Fitness Monitor Instruction Manual for Cycle Ergometry, Furnished with USAF SCE Prototype Software)

Appendix G:
Initial Power Output Settings for the Baseline USAF SCE

TABLE 2
INITIAL WORK LOAD REQUIREMENTS (kiloponds)

Age 17 - 35 yr			36 - 50 yrs		Over 50 yrs	
Weight (lbs)	Active*	Inactive	Active*	Inactive	Active*	Inactive
MALE						
Below 130	1.5	1.0	1.5	1.0	1.5	1.0
131 - 150	2.0	1.5	1.5	1.5	1.5	1.0
151 - 180	2.0	2.0	2.0	2.0	2.0	1.5
181 - 220	2.5	2.0	2.0	2.0	2.0	1.5
Above 220	2.5	2.5	2.5	2.0	2.0	1.5
FEMALE						
Below 120	1.0	1.0	1.0	1.0	1.0	1.0
121 - 140	1.5	1.0	1.5	1.0	1.0	1.0
141 - 160	1.5	1.0	1.5	1.0	1.0	1.0
161 - 180	2.0	1.5	2.0	1.5	1.5	1.0
Above 180	2.0	2.0	2.0	1.5	1.5	1.0

*Active = subject is jogging, swimming, cycling or playing vigorous sports regularly for at least 20 minutes per day, 3 days per week, for the past 90 days to qualify as active. Lawn or garden work does not qualify as active.

(From: Unit Fitness Monitor Instruction Manual for Cycle Ergometry, Furnished with USAF SCE Prototype Software)

Appendix H:
USAF SCE Computer Software
Recommended Power Output Adjustments

(From: Lt. Col. Roger Bisson, N.D.: Personal Communication, 1994)

LOAD SETTING GUIDE
LOAD ADJUSTMENT TABLE FOR CYCLE ERGOMETRY

AGE GROUP: 13-29 YEARS

TIME	HEART RATE	APPROPRIATE LOAD CHANGE
End First Min	Less Than 110	ADD 1.0
	110-119	ADD 0.5
	120-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Second Min	Less Than 110	ADD 1.0
	110-119	ADD 0.5
	120-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Third Min	Less Than 115	ADD 1.0
	115-128	ADD 0.5
	129-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test

End of minutes 4 through 9: Stop test when heart rate exceeds Maximum Desired Heart Rate. Maximum Desired Heart Rate = (85%x(220-Age))

AGE GROUP: 30-39 YEARS

TIME	HEART RATE	APPROPRIATE LOAD CHANGE
End First Min	Less Than 105	ADD 1.0
	105-114	ADD 0.5
	115-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Second Min	Less Than 110	ADD 1.0
	110-119	ADD 0.5
	120-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Third Min	Less Than 115	ADD 1.0
	115-128	ADD 0.5
	129-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test

End of minutes 4 through 9: Stop test when heart rate exceeds Maximum Desired Heart Rate. Maximum Desired Heart Rate = (85%x(220-Age))

AGE GROUP: 40-49 YEARS

TIME	HEART RATE	APPROPRIATE LOAD CHANGE
End First Min	Less Than 100	ADD 1.0
	100-109	ADD 0.5
	110-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Second Min	Less Than 100	ADD 1.0
	100-119	ADD 0.5
	120-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Third Min	Less Than 105	ADD 1.0
	105-122	ADD 0.5
	123-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test

End of minutes 4 through 9: Stop test when heart rate exceeds Maximum Desired Heart Rate. Maximum Desired Heart Rate = (85%x(220-Age))

AGE GROUP: 50-59 YEARS

TIME	HEART RATE	APPROPRIATE LOAD CHANGE
End First Min	Less Than 100	ADD 1.0
	100-109	ADD 0.5
	110-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Second Min	Less Than 100	ADD 1.0
	100-119	ADD 0.5
	120-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Third Min	Less Than 105	ADD 1.0
	105-120	ADD 0.5
	121-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test

End of minutes 4 through 9: Stop test when heart rate exceeds Maximum Desired Heart Rate. Maximum Desired Heart Rate = (85%x(220-Age))

AGE GROUP: 60-69 YEARS

TIME	HEART RATE	APPROPRIATE LOAD CHANGE
End First Min	Less Than 90	ADD 1.0
	90-104	ADD 0.5
	105-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Second Min	Less Than 90	ADD 1.0
	90-109	ADD 0.5
	110-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test
End Third Min	Less Than 95	ADD 1.0
	90-105	ADD 0.5
	106-(85%x(220-Age))	No Change
	(85%x(220-Age))-180	Recommend Test Termination
	Above 180	Stop Test

End of minutes 4 through 9: Stop test when heart rate exceeds Maximum Desired Heart Rate. Maximum Desired Heart Rate = (85%x(220-Age))

Appendix I:
Data Sheet for USAF SCE Tests

University of Florida
Ctr. for Exercise Sci.
Room 27 Florida Gym
Gainesville, FL 32611
(904) 392-9575

**United States Air Force Study 1993:
Cross Validation of Submaximal Cycle Ergometry
Estimates of Aerobic Capacity**

Subject ID#: ______
Classification: ______
Sex: ______

STATION #: ______ **TESTERS:** ______

Name: ______ **Age:** ______ **Ht:** ______ cm ______ in **Wt:** ______ kg ______ lb

Baseline SCE
Date______
Time______
Weight______
Temp______
Hum.______
MaxHR Limit______

Time	Kp	HR		RPE	
		P	E	O	L
Rest					
0-1					
1-2					
2-3					
3-4					
4-5					
5-6					
6-7					
7-8					
8-9					
9-10					

RPE: ______
Aerobic Capacity: ______
Fit. Categ.: ______

SCE-______
Date______
Time______
Weight______
Temp______
Hum.______
MaxHR Limit______
Prev Valid Kp______

Time	Kp	HR		RPE	
		P	E	O	L
Rest					
0-1					
1-2					
2-3					
3-4					
4-5					
5-6					
6-7					
7-8					
8-9					
9-10					

RPE: ______
Aerobic Capacity: ______
Fit. Categ.: ______

SCE-______
Date______
Time______
Weight______
Temp______
Hum.______
MaxHR Limit______
Prev Valid Kp______

Time	Kp	HR		RPE	
		P	E	O	L
Rest					
0-1					
1-2					
2-3					
3-4					
4-5					
5-6					
6-7					
7-8					
8-9					
9-10					

RPE: ______
Aerobic Capacity: ______
Fit. Categ.: ______

SCE-______
Date______
Time______
Weight______
Temp______
Hum.______
MaxHR Limit______
Prev Valid Kp______

Time	Kp	HR		RPE	
		P	E	O	L
Rest					
0-1					
1-2					
2-3					
3-4					
4-5					
5-6					
6-7					
7-8					
8-9					
9-10					

RPE: ______
Aerobic Capacity: ______
Fit. Categ.: ______

SCE-______
Date______
Time______
Weight______
Temp______
Hum.______
MaxHR Limit______
Prev Valid Kp______

Time	Kp	HR		RPE	
		P	E	O	L
Rest					
0-1					
1-2					
2-3					
3-4					
4-5					
5-6					
6-7					
7-8					
8-9					
9-10					

RPE: ______
Aerobic Capacity: ______
Fit Cat.: ______

Appendix J:
Borg Scale of Rating of Perceived Exertion'

RATING OF PERCEIVED EXERTION

Category	RPE Scale
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

(From Borg GA: *Med Sci Sports Exerc* 14:377-387, 1982)

During the timed exercise test, we want you to pay close attention to how hard you *feel* the work rate is. This feeling should be your total amount of exertion and fatigue, combining all sensations and feelings of physical stress, effort, and fatigue. Don't concern yourself with any one factor such as leg pain, shortness of breath, and exercise intensity, but try to concentrate on your *total inner* feeling of exertion. Don't underestimate or overestimate, just be as accurate as you can.

Appendix K:
Low, Medium and High Fitness Classification
by Estimated Aerobic Capacity ($\dot{V}O_{2max}$ $ml \cdot kg^{-1} \cdot min^{-1}$) and
Desired Distribution of Volunteers as Shown in
"Statement of Work" (Table B) and as Modified by
Lt. Col. Roger Bisson, M.D., USAF,
on November 8, 1993 (Table A).

Table A modified, Dr. Bisson

MALES AGE RANGES

Fitness Category	$\dot{V}O_{2max}$	17-24	25-29	30-34	35-39	40-44	45-49	50-54
Low	<35ml/kg/min	4	4	4	4	4	4	4
Medium	≥35<44	3	3	3	3	3	3	3
High	≥44	3	3	3	3	3	3	3

FEMALES AGE RANGES

Fitness Category	$\dot{V}O_{2max}$	17-24	25-29	30-34	35-39	40-44	45-49	50-54
Low	<29ml/kg/min	4	4	4	4	4	4	4
Medium	≥29<37	3	3	3	3	3	3	3
High	≥37	3	3	3	3	3	3	3

Table B original statement of work

MALES AGE RANGES

Fitness Category	$\dot{V}O_{2max}$	17-24	25-29	30-34	35-39	40-44	45-49	50-54
Low	<32ml/kg/min	4	4	4	4	4	4	4
Medium	≥32<44	3	3	3	3	3	3	3
High	≥44	3	3	3	3	3	3	3

FEMALES AGE RANGES

Fitness Category	$\dot{V}O_{2max}$	17-24	25-29	30-34	35-39	40-44	45-49	50-54
Low	<26ml/kg/min	4	4	4	4	4	4	4
Medium	≥26<37	3	3	3	3	3	3	3
High	≥37	3	3	3	3	3	3	3

Appendix L:
Physicians' Subject Evaluation Form

HISTORY AND PHYSICAL

Name____________________ Age______ Sex______
Date of exam____________ Time________ Race________

Cardiovascular History:	Yes	No	Date of Onset	Duration	Meds
Angina pectoris					
Palpitations					
Dyspnea on exertion					
PND					
Orthopnea					
Claudication					
TIA's					
CVA					

Chronic Medical Conditions: ______None ________Listed below
1.____________________ Date of Onset________
2.____________________ Date of Onset________
3.____________________ Date of Onset________
4.____________________ Date of Onset________

Cardiovascular Risk Factors: _____Cigarettes _____HTN _____Diabetes
_____Family History _____Cholesterol

Current Medications:	Dose	Duration

Previous Surgeries:	Date

Review of Systems (positives only)

____
____
____

Physical Exam: Pulse ____________ BP ________ RR ________
Head and Neck _____NL _____Abnl_______________
Lungs ____Nl _____Abnl_______________
Heart: ____Nl _____Abnl_______________
Abdomen: ____Nl_____Abnl_______________
Extremities ____Nl _____Abnl_______________
Pulses:____Nl_____Abnl_______________
Neuro: ____Nl_____Abnl_______________

12 lead ECG: Rate_____Rhythm_______Axis_________Nl__________

Abnormal____________________________________

Impression:

____
____

____
Physician

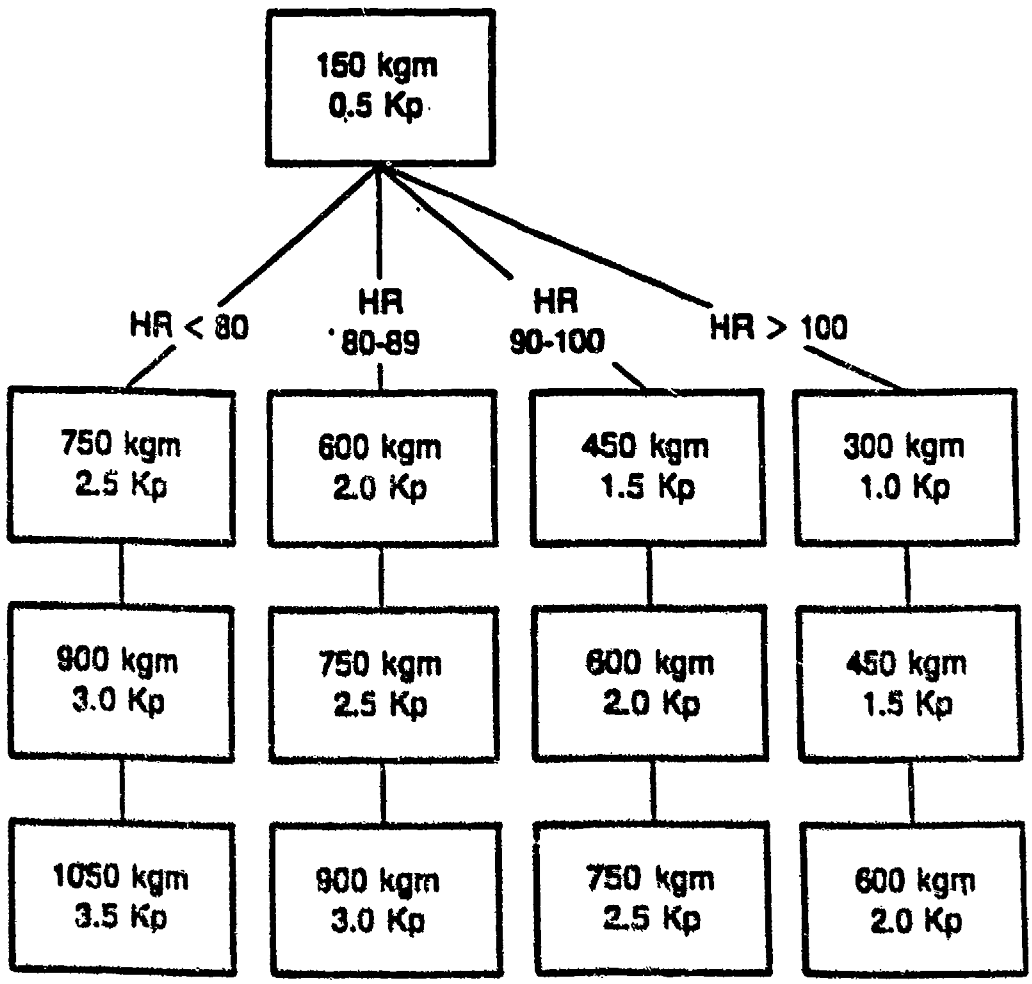
Appendix M:
The Bruce Protocol for Maximal Treadmill Tests

Exercise Time (min.)	Treadmill Speed (MPH)	Treadmill Grade (%)
1	1.7	10
2	1.7	10
3	1.7	10
4	2.5	12
5	2.5	12
6	2.5	12
7	3.4	14
8	3.4	14
9	3.4	14
10	4.2	16
11	4.2	16
12	4.2	16
13	5.0	18
14	5.0	18
15	5.0	18
16	5.5	20
17	5.5	20
18	5.5	20
19	6.0	22
20	6.0	22
21	6.0	22

Appendix N:
Modified Astrand-Saltin Maximal Cycle Ergometer Protocol (60 RPM) Used for USAF Validation Study

Exercise Time (min)	Power Output (Males, Kpm)	Power Output (Females, Kpm)
1	360	360
2	360	360
3	720	540
4	720	540
5	1080	720
6	1080	720
7	1440	900
8	1440	900
9	1800	1080
10	1800	1080
11	2160	1260
12	2160	1260
13	2520	1440
14	2520	1440
15	2880	1620

Appendix O:
Flow Chart for YMCA SCE Test
(50 RPM)



(From: The Y's Way to Physical Fitness, Human Kinetics Publishers, Champaign, IL, 1989)

Appendix P
Cycle Ergometry Fitness Categories
Aerobic Capacity by Age for Men and Women

	AGE (Men)			
Fitness Category	<29	30-39	40-49	>50
Category I	< 28.0	< 27.0	< 25.0	< 22.0
Category II	28.0-33.9	27.0-31.9	25.0-29.5	22.0-27.5
Category III	34.0-41.9	32.0-38.9	29.6-35.5	27.6-31.5
Category IV	42.0-47.9	39.0-45.9	35.6-41.5	31.6-36.5
Category V	48.0-54.9	46.0-52.9	41.6-47.5	36.6-42.5
Category VI	> 54.9	> 52.9	> 47.5	> 42.5

	AGE (Women)			
Fitness Category	<29	30-39	40-49	>50
Category I	< 26.0	< 24.0	< 23.0	< 20.0
Category II	26.0-26.9	24.0-25.9	23.0-25.9	20.0-22.9
Category III	27.0-35.9	26.0-33.9	26.0-30.9	23.0-25.9
Category IV	36.0-42.9	34.0-38.9	31.0-36.9	26.0-30.9
Category V	43.0-48.9	39.0-46.9	37.0-40.7	31.0-34.9
Category VI	> 48.9	> 46.9	> 40.7	> 34.9

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